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HAROLD BELMONT PRICE

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OF ELECTRONIC CIRCUITS

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TINKERTOY MODULIZATION

OF ELECTRONIC CIRCUITS

by
Harold Belmont Price,
Lieutenant, United States Navy

Submitted in partial fulfillment
of the requirements
for the degree of
MASTER OF SCIENCE IN
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[redacted]

This work is accepted as fulfilling
the thesis requirements for the degree of

MASTER OF SCIENCE IN
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from the
United States Naval Postgraduate School

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PREFACE

The information included in the following thesis was gathered while assigned to work as a junior project engineer at Sanders Associates Incorporated, Nashua, New Hampshire, as part of the industrial experience program of the Electronics Curriculum, U. S. Naval Postgraduate School, Monterey, California. While assigned to this duty during the Spring term of 1953, visits were also made to the National Bureau of Standards, Arlington, Virginia laboratory where the pilot production line for evaluating the Tinkertoy system was in the final stages of installation and adjustment before production was started. By the middle of this year the machine production of the equipment selected to be produced for evaluation of the system should have been started. Prior to machine production a sufficient number of this equipment will have been made by hand in the module form to permit testing under operational conditions so that necessary modifications may be made before large numbers are made in the machines.

Although the system is still under development at this writing so that a detailed report may rapidly be made obsolete, it is felt that for a better understanding of the system and the problems involved such treatment is justified. For a more generalized treatment of the subject, the reader is referred to a thesis by Lieutenant John E. Hart who was assigned to duty at Sanders Associates at this same time.

The detailed information included herein is primarily based upon the methods used at Sanders Associates where a small module facility has been established to manually produce module circuitry as required by

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their project engineers who are redesigning a number of equipments for machine production. Where major differences are known to exist between the methods used by Sanders Associates and those to be used by the National Bureau of Standards in the machines, an attempt will be made to mention those differences.

Many problems have arisen in the redesign of complicated electronic equipment which have required long hours of work on the part of both the circuit and the component engineers to find solutions. The method is still so new and for security reasons so few people have been brought in to work on the project that many of the problems remaining unsolved only await the engineers to find time to devote to their solutions.

I wish to acknowledge the invaluable assistance given me by the engineers and technicians of Sanders Associates in giving freely of their time and experience to provide the necessary information for preparation of this thesis. Thanks are also due Mr. R. L. Henry and Mr. A. Ripnitz of the National Bureau of Standards who have taken time from their busy schedules to explain the Tinkertoy system and its concepts and especially for providing the information on the pilot production plant.

Monterey, California.

April 27, 1953.

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LIST OF ILLUSTRATIONS

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TABLE OF ABBREVIATIONS

Coeff.	coefficient
cps	cycles per second
Diam.	diameter
^{o}C	temperature in degrees centrigrade
^{o}F	temperature in degrees fahrenheit
FM	frequency modulation
gm	weight in grams
K	preceding a number indicates dielectric constant following a number indicates resistance in kilohms
M	resistance in megohms
Mc	frequency in megacycles per second
mf	capacitance in microfarads
mh	inductance in microhenries
mmf	capacitance in micromicrofarads
mV	voltage in microvolts
mV/V	microvolts per volt
NBS	National Bureau of Standards
ppm/^{o}C	parts per million per degree centrigrade
r-f	radio frequency
Temp.	temperature
V	volts
"	inches

[redacted]

I. INTRODUCTION

Cheaper and more rapid methods of producing electronic equipment have slowly evolved as the industry has been forced to meet close competition. However, the methods developed have in general been designed to speed up the production of only some particular part or some particular equipment. Assembly line methods in which large numbers of relatively unskilled workers are assigned small repetitive tasks have proven uneconomical, except where very large numbers of one particular equipment is to be produced.

The greatly increased demand from the armed forces for large quantities of many different types of electronic equipment during World War II made apparent the shortcomings of the existing methods of production. A method is needed which is readily adaptable to rapid production of both large and small quantities of a given type of electronic equipment and which at the same time will place less demand upon the material and manpower resources of the country.

The National Bureau of Standards during World War II developed printed circuits to permit rapid production of VT proximity fuzes which were required in large numbers for use in gun projectiles. With the methods used in this development it was found that the percentage yield of acceptable circuits was undesirably low where several lumped components were printed as part of the circuit. To partially offset this shortcoming adhesive tape resistors which are described in reference (4) were developed. Many different printed circuit techniques have been used since information concerning the VT fuze

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development was first released in February of 1946. A discussion of these techniques may be found in references (1) to (3).

A widely publicized development by Sargrove Limited made use of printed circuit methods in the automatic machine production of a broadcast band radio receiver. The process which is described briefly in references(7) and (8) was abandoned, at least temporarily, when the anticipated market for the receivers failed and it was found to be uneconomical to convert the machines for production of other equipment.

A method of machine assembly of electronic circuitry has been developed for the Signal Corps which is described in references (6) and (9) under the name Auto-Sembly. In this method the conducting circuits are "printed" on insulated subassembly chassis cards. Conventionally produced type components are machine inserted in holes drilled through the cards and then dip-soldered to the conductors on the cards. A machine assembly process making use of conventional components is also being developed for the Air Force. At least one company is known to be working on a machine production process for their own use.

A somewhat different approach, where printed circuits were not used, was developed for machine assembly of an airborne intercom amplifier. This process is described in reference (5). All components were reduced to a cylindrical form with radial leads. The components were stacked in a cylindrical module with electrical connections to each other and to external circuits made through nine riser wires woven into an insulating wrapper which provided mechanical rigidity.

The cylindrical components were hopper fed to an automatic indexing and soldering machine which required the one operator to perform only simple steps.

Many other examples are available where machine processes have been used to a limited extent, but with the exception of the Sargrove venture in producing a relatively simple circuit no attempt has been made to completly machine produce an equipment from bulk or slightly machined materials. The Bureau of Aeronautics became aware of the possibilities of developing such a system and in June 1950 inaugurated the Tinkertoy project as an Industry Preparedness Measure Project. This project is described in references (C1) and (C2). Technical direction was placed under the National Bureau of Standards to take advantage of the experience of that group in basic components development. The objectives of the Tinkertoy Project as stated in reference (C1) are:

a. Eliminate the availability of trained skilled labor as the limiting function of the Nation's capacity to produce the large quantities of military electronic equipment which will be required with minimum delay in the event of mobilization, and replace it with a like capacity in the form of machine tools in reserve.

b. Reduce the astounding cost to the Country's taxpayers of military electronic equipment through savings in manpower and materials.

c. Reduce the usage rate of several critical materials.

d. Simplify the maintenance problem on complex military electronic equipment and thereby improving the tactical usability and

reducing the requirements of almost unattainable numbers of highly trained maintenance technicians.

To fulfill these objectives it appeared necessary to depart from usage of conventionally produced components and instead to machine produce the components needed. The system developed must provide for rapid, economical conversion from production of one equipment to production of another. Since rapid expansion of the production capacity was required, it appeared desirable to use machines which could themselves be mass-produced and wherever possible to use standard machines already in production which would require only minor modification at the most. The machines should also be small and relatively inexpensive so that large numbers could be stored in reserve, and so that if it became necessary to use them they could be easily handled and rapidly installed in small factories already built.

After a short period of analysis it was decided to use printed circuit type components in the modular type of construction to be described. Full emphasis was placed upon early establishment of a pilot production facility which would permit evaluation of the system on a production scale.

The system of construction chosen was required to be satisfactory from an electronics aspect as well as being compatible with mechanized production techniques. In this respect the resulting equipment must be reliable, stable, and rugged. The machines must not be unduly complicated so they would be difficult to manufacture. The system of construction and the methods of production must provide for sufficient

flexibility so that changes necessary to shift from production of one equipment to another are minimized and the changes that are required may be made quickly and economically. This latter provision should permit the production process to be readily adapted for production of either large or small quantities of a particular equipment. The components must be produced in the mechanized production facility in so far as practical, and with minimum use of critical materials. Provision must be made, however, for inclusion of non-machine produced components in the assembly process with minimum disruption.

The system developed for use in Tinkertoy makes use of ceramic wafers upon which the machine produced circuit components are mounted. Riser wires are soldered to notches in the wafer edges for holding the wafers in parallel stacks and for providing electrical connections required to the various components. Each module, as the stacks of wafers are called, generally includes the vacuum tube and associated circuitry required by one stage of the circuit. The modules are secured between top and bottom baseplates which are etched with the necessary circuitry for connecting the modules electrically. The Tinkertoy system at present is limited to production of these plate assemblies which in general contain the circuitry of functional subassemblies. A complete equipment will usually contain several plate assemblies plus mechanical parts and any conventional components which are not adaptable to modulization.

In the following two chapters the various components and the machine methods of producing and assembling them will be described

in detail. This will be followed by a discussion of the design problems peculiar to the Tinkertoy method of construction. The final chapter will be devoted to a discussion of the effects which may be expected to result from the development of the Tinkertoy system.

II. COMPONENTS

The development of components for the Tinkertoy system and the machines to produce them has been advanced to the state where machine production of electronic circuits appears reasonably certain of success. Considerable effort is continuing to be expended towards improving the present components as well as toward developing new components, adaptable to machine production, which will further reduce the occasional need to resort to components not produced in the Tinkertoy system. Cataloging of commercially available components of a size adaptable to being packaged in modules or modular size packages has been undertaken.

Frequent changes in the Tinkertoy system are still being made so that any detailed report runs the hazard of rapidly becoming obsolete. It is felt, however, that a better understanding can be obtained from a consideration of the problems and details than from a generalized discussion. For this reason the treatment followed will be that of presenting the more important details of the present system. In this chapter the methods of making the components will be discussed and in the next chapter the machine processes will be described. The characteristics to be considered by the designer will be included in the chapter on design.

The information presented is primarily based on the methods used at Sanders Associates where a small module assembly facility has been established to manufacture the components and plate assemblies required by the engineers redesigning electronic equipment for machine production using the Tinkertoy system. The methods to be used in the pilot production

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line will also be indicated where different methods are known to be used. References (4) and (C1) through (C3) have been consulted freely to provide much of the following information.

1. Modular Wafer

The circuit components are mounted on the modular wafers which are the key to the Tinkertoy system of construction. The wafer is a square ceramic plate which is about seven-eighths of an inch on a side and about one-sixteenth of an inch thick. Three equally spaced notches on each edge are designed to receive the riser wires which are soldered to the wafer in assembly of the module. A fourth notch placed between two of the riser wire notches on one edge is provided for use in indexing the wafers to the correct orientation during the assembling processes. Several different variations of this basic wafer are made for specific purposes as will be mentioned later. Pictures of the various forms of wafers are shown in figures (1) to (3) and (7) to (9).

The wafers are made of steatite or talc which is thoroughly mixed with water and then pressed dry into flat cakes. The caked steatite is granulated to cornmeal size particles and hopper fed to a die-press which compresses the steatite into the desired shape. The wafers which are now strong enough to be handled are fired for eight hours at 2300°F.

The notches of the wafer are painted with silver paint to provide a surface to which the riser wires may be soldered. As will be described later, the conducting pattern which provides the electrical connection between the components and the riser wire notches of a wafer are also painted on with silver paint. The riser wires provide the electrical connection between the components on different wafers.

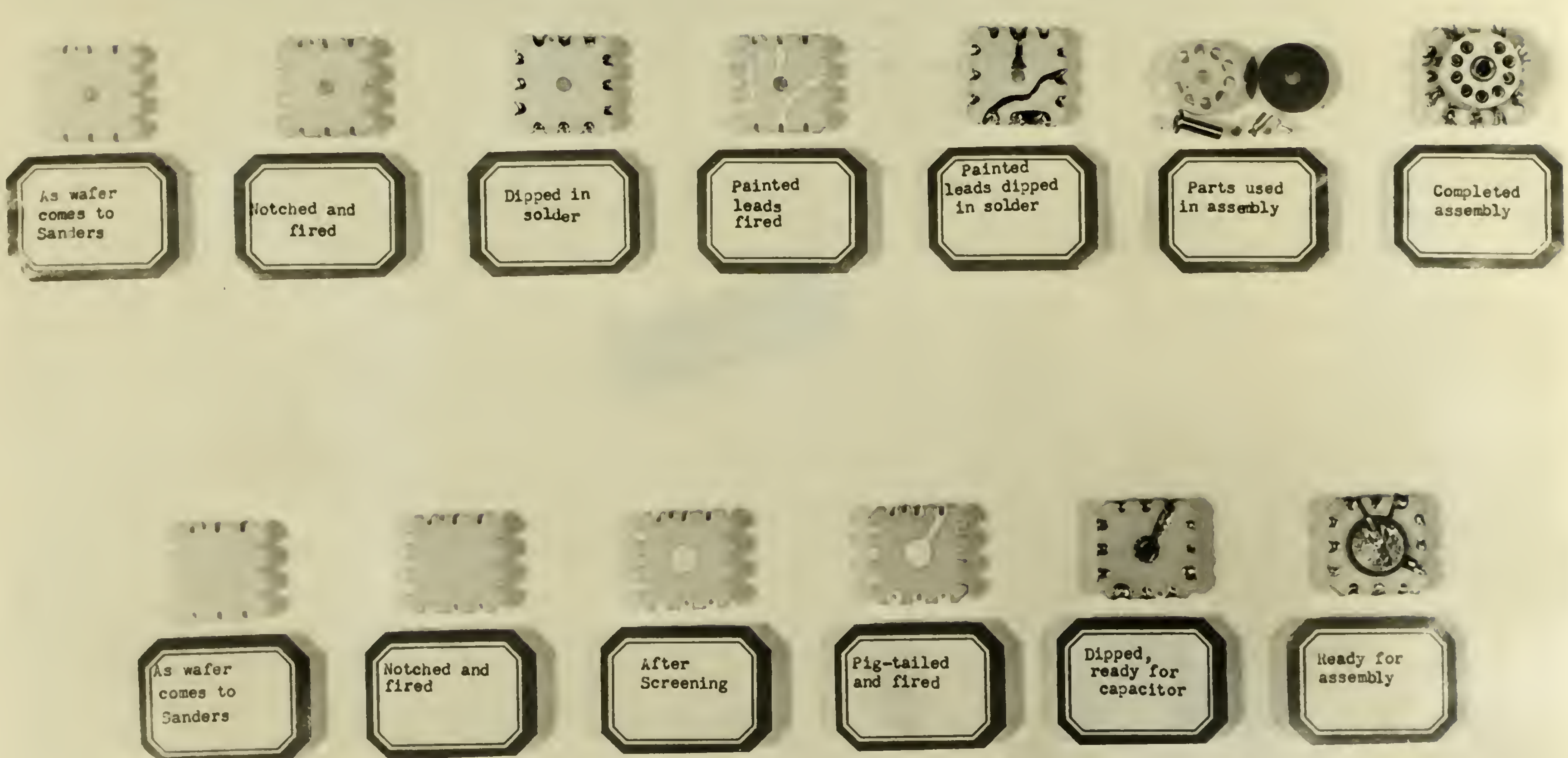

Figure 1
Top: Progressive assembly of a tube socket to a wafer.
Bottom: Progressive assembly of a disc capacitor to a wafer.

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2. Capacitors

The basic capacitor of the Tinkertoy system is a flat ceramic disc dielectric with the two plates silver painted on opposite faces. These capacitors have been standardized to be about eighteen mils thick and either thirty or fifty-five hundredths of an inch in diameter.

A second type which is adaptable to machine production has been developed to provide a stable capacitor at high values of capacitance where the ceramic dielectric becomes unstable with temperature. This capacitor is wound or folded in modular size using aluminum foil plates and a mylar film dielectric.

(a) Ceramic disc capacitors

The ceramic disc capacitor bodies are made of Barium Titanate mixed with various metallic oxides to obtain a wide selection of dielectric constants. Different dielectric constants are selected to provide a complete range of capacitance values from 7 mmf up to .01 mf. The specific mixtures used have been selected as being the most suitable in the various ranges for making capacitors, and to provide some choice of the temperature coefficient.

After a thorough mixing the selected mixture is formed into the desired size capacitor discs and then fired at 2700°F.

Within the range of capacitance values available with each dielectric the particular capacitance is determined by selection of the proper size electrode areas which are silk-screened on the faces of the capacitance bodies in silver paint. Typical capacitance values obtained with different dielectrics and various diameter electrodes are given in table I.

[redacted]

TABLE I

Dielectric Constant	Capacity in mmf for various front electrode diameters					With back electrode diameter in inches
	4/16"	5/16"	6/16"	7/16"	8/16"	
10	4	6	8	12	--	7/16
13.6	5	--	--	18	--	7/16
16.7	15	22	27	33	--	7/16
28.4	12	--	--	--	--	7/16
29.6	22	33	44	47	--	7/16
57.2	39	75	88	120	--	7/16
64.9	45	70	92	120	--	7/16
88	--	68	--	120	150	8/16
317.5	180	270	--	--	--	5/16
	--	--	330	--	--	6/16
	200	--	430	530	--	7/16
508.3	330	500	625	880	--	7/16
544.5	220	--	--	--	--	4/16
	270	390	560	680	--	7/16
2000	1000	--	--	--	--	6/16
	1100	1550	2440	2700	--	7/16
2136	1200	1500	--	--	--	7/16
5000	2200	3300	4700	6800	10,000	8/16
6000	--	3100	7500	10,000	--	7/16

[redacted]

More than one capacitor can be placed on a single disc by dividing one face into a number of sectors.

The silver is cured by firing for ten minutes at 1350^{o}F with the method used at Sanders Associates but will be a longer process in the pilot production line. After this final high temperature process the dielectric must age before a stable value of capacitance is reached. Any appreciable increase in temperature such as in pre-tinning and soldering the capacitor to the module wafer will result in a temporary deviation from the stable value of capacitance.

The disc capacitor and the wafer upon which it is to be soldered are both pre-tinned by dip-soldering. In manual assembly the capacitor is soldered to the wafer in the dip-soldering process, but in the machine process the previously pre-tinned components are soldered together by heating the assembled parts to the melting point of the tinning solder. One plate of the capacitor is electrically connected to one of the riser wire notches of the wafer through the pattern silvered onto the wafer and the other plate of the capacitor is connected to a second riser wire notch by a thin silver ribbon.

The steps in assembly of the disc capacitor to a module wafer are shown in figure 1. The various types of capacitors are pictured in figure (2).

(b) Mylar film capacitors

The mylar film capacitor is made by placing the two plates of aluminum foil ribbon between insulating layers of mylar film ribbon and winding on a thin flat arbor the proper number of turns for the

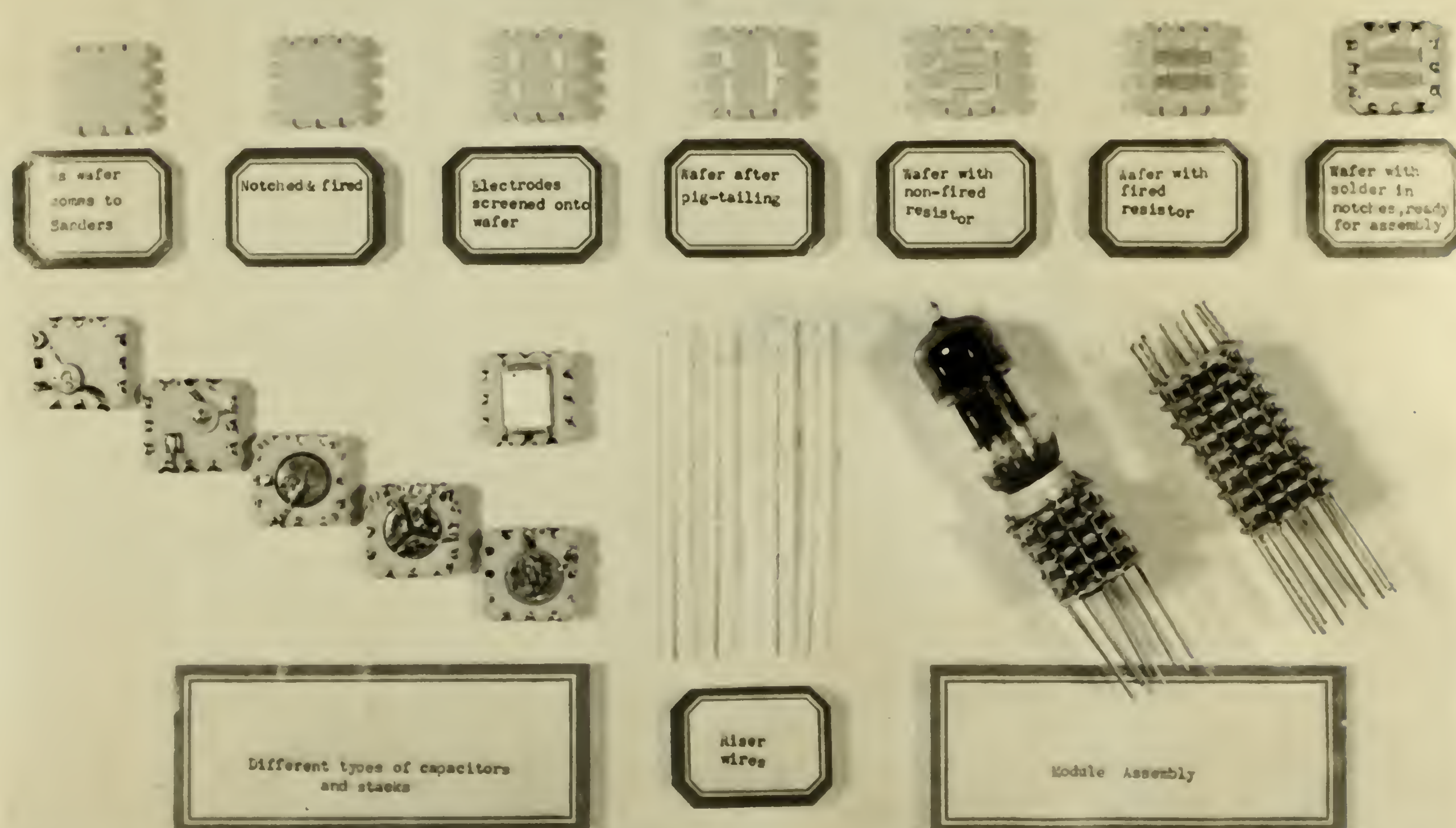

Figure 2
Top: Progressive assembly of tape resistors to a wafer.

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capacitance desired. Low voltage capacitors, for up to fifty volts, require only single layers of mylar film, but higher voltage capacitors require double layers of mylar film. Future developments are aimed towards producing a "non-inductive" capacitor by folding the capacitor rather than winding as at present.

After winding the arbor is removed and the capacitor is compressed between two flat plates while being heated for two hours at 200°C to thermoset the mylar film. Tinned copper wire pigtails are tack-welded to the two aluminum foil plates and soldered to the module wafer notches for making electrical connections to the proper riser wires. The capacitor is physically secured to the wafer with an adhesive cement.

The aluminum foil ribbon used in the mylar capacitor is about three-tenths of a mil thick and of various widths as also is the mylar film ribbon which is about one quarter mil in thickness. The maximum thickness of the completed capacitor is about ninety mils. This permits only tape resistor components on the face of the adjacent wafer. The range of capacitance available with present mylar film capacitors varies from about 680 mmf to .02 mf. Operation up to 125°C is permissible.

Construction of the mylar capacitor is shown in figure (3) and a completed capacitor is shown in figure (2).

(c) Capacitor developments

Recent investigations of the Nyobates for capacitor dielectrics have shown considerable promise for obtaining high dielectric constant bodies which are temperature stable. No attempt has yet been made to

Figure 3
Top: Mylar capacitor construction.
Bottom: Assembly of slug-tuned inductance.

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[redacted]

make ceramic disc capacitors for the Tinkertoy system using these dielectrics; but if the early indications prove out it will become possible to make high value stable disc capacitors in the Tinkertoy system.

3. Resistors

The carbon film tape resistor developed by the National Bureau of Standards for use in printed circuit applications has been adopted as the standard resistor for use in the Tinkertoy system. For applications where carbon resistors do not provide the required precision and stability a wire-wound modular resistor is being developed. A miniaturized variable resistor has been mounted on a module wafer for use where needed.

(a) The tape resistor, described in reference (4), is produced by spraying a carbon-resin emulsion on asbestos paper tape. The presently available range of values from forty ohms to ten megohms is obtained by changing the resin to carbon ratio and by changing the size of carbon particles used. The individual resistors are cut from the tape and applied to the painted silver electrodes of the module wafer. The resistor size has been standardized to be about one-eighth of an inch wide and one-half of an inch long with the wafer electrodes separated by three-tenths of an inch. The power dissipation rating has been established to be one-quarter of a watt for operation up to 150°C in one series of resistors and up to 200°C for another series.

The resistance obtained from a given formulation is affected by a number of factors such as the tape used, the spray adjustments of the spray gun, and the characteristics of the spray emulsion. The

National Bureau of Standards has sufficient information that it is possible for them to predict the value of resistance to be obtained with a given combination within ten per cent. It is expected that with receipt of a more accurate balance for determining the quantities to be placed in a given mixture that a better accuracy of prediction will be possible. Sanders Associates, due to relative inexperience in making the tape resistors and inability to obtain the type asbestos tape used by the National Bureau of Standards, have not yet been able to meet these results.

The tape used in producing the resistors is a short fiber asbestos tape of a type similar to that available commercially for use in electrical insulation. The tape is impregnated with a polyvinyl acetate or with a silicone resin binder which gives the tape sufficient strength to permit handling. The commercially available silicone resin tape has a greater percentage of impregnant than does the special laboratory produced tape used by the National Bureau of Standards. The silicone resin impregnant from the tape apparently goes into solution with the silicone resin of the sprayed resistor mixture when the tape is heated in curing, resulting in a higher value of resistance than would otherwise be obtained. More important, the amount of impregnant entering into solution cannot be accurately controlled, resulting in a loss of uniformity and in a decrease of accuracy with which the resulting resistance value can be predicted. This effect is minimized with the tape especially prepared for the National Bureau of Standards. The necessity of using a specially prepared tape does not present a great problem for even if the entire electronics industry were to start using tape resistors, the small amount of asbestos tape required could be easily made on a laboratory scale. The polyvinyl acetate

impregnated tape is limited to operation up to 150°C, but the silicone resin impregnated tape permits operation up to 200°C.

The resistor mixture which is sprayed on the tape consists of a carbon particle conducting medium with a silicone resin insulating binder and a butyl cellusolve thinner. The binder which largely determines the operating temperature limit of the resistor serves: (1) to hold the carbon particles in a fixed position to aid in fixing the resistance value, (2) to secure the carbon conductor to the asbestos tape and the tape to the module wafer, and (3) to provide some protection to the resistor from abrasion and the effects of humidity.

Major changes of resistance values are obtained by altering the resin to carbon ratio, and smaller changes are obtained by using different carbons having different size particles. The higher ranges of resistance values are obtained with the higher resin to carbon ratios. The lower values of resistance within a given range are obtained using large particle size carbons such as graphite. The medium resistance values are obtained using medium size particles such as the furnace blacks and the high resistance values are obtained using small size particles such as in the channel blacks. A change of particle size tends to change the resistance value approximately in inverse proportion to the ratio of the particle diameters.

Curves of resistance versus resin to carbon ratios for typical carbons used in making tape resistors are given in figures (4) to (6). Some of the characteristics of several carbons are given in table II. The preferred carbons for various ranges of resistance, as determined by the National Bureau of Standards in development of the tape resistor, are given in table III.

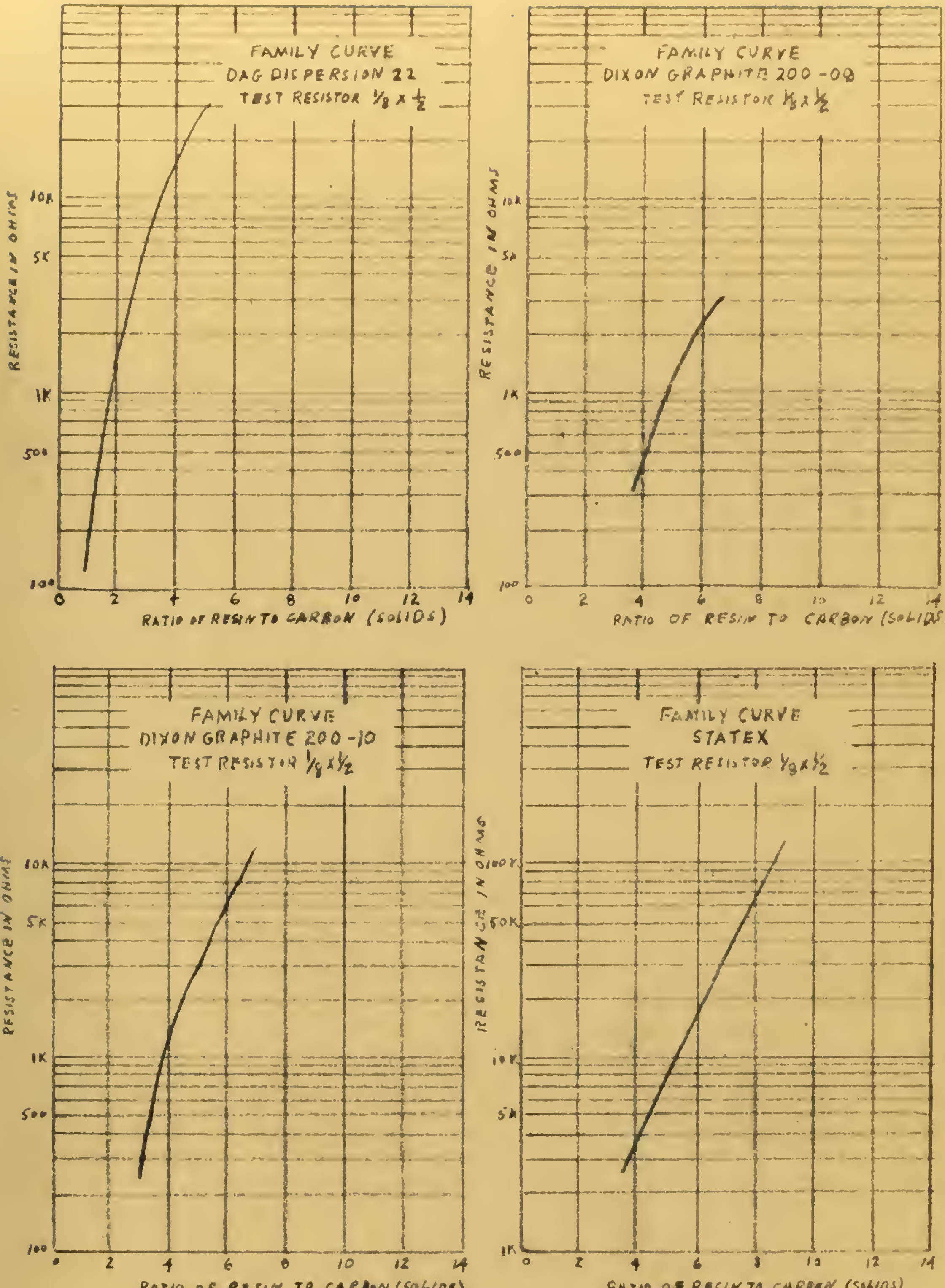

FAMILY CURVE
DAG DISPERSION 22
TEST RESISTOR 1/8 x 1/2
RESISTANCE IN OHMS
10K
5K
1K
500
100
0 2 4 6 8 10 12 14
RATIO OF RESIN TO CARBON (SOLIDS)
FAMILY CURVE
DIXON GRAPHITE 200-08
TEST RESISTOR 1/8 x 1/2
RESISTANCE IN OHMS
10K
5K
1K
500
100
0 2 4 6 8 10 12 14
RATIO OF RESIN TO CARBON (SOLIDS)
FAMILY CURVE
DIXON GRAPHITE 200-10
TEST RESISTOR 1/8 x 1/2
RESISTANCE IN OHMS
10K
5K
1K
500
100
0 2 4 6 8 10 12 14
RATIO OF RESIN TO CARBON (SOLIDS)
FAMILY CURVE
STATEX
TEST RESISTOR 1/8 x 1/2
RESISTANCE IN OHMS
100K
50K
10K
5K
1K
0 2 4 6 8 10 12 14
RATIO OF RESIN TO CARBON (SOLIDS)

Figure 4

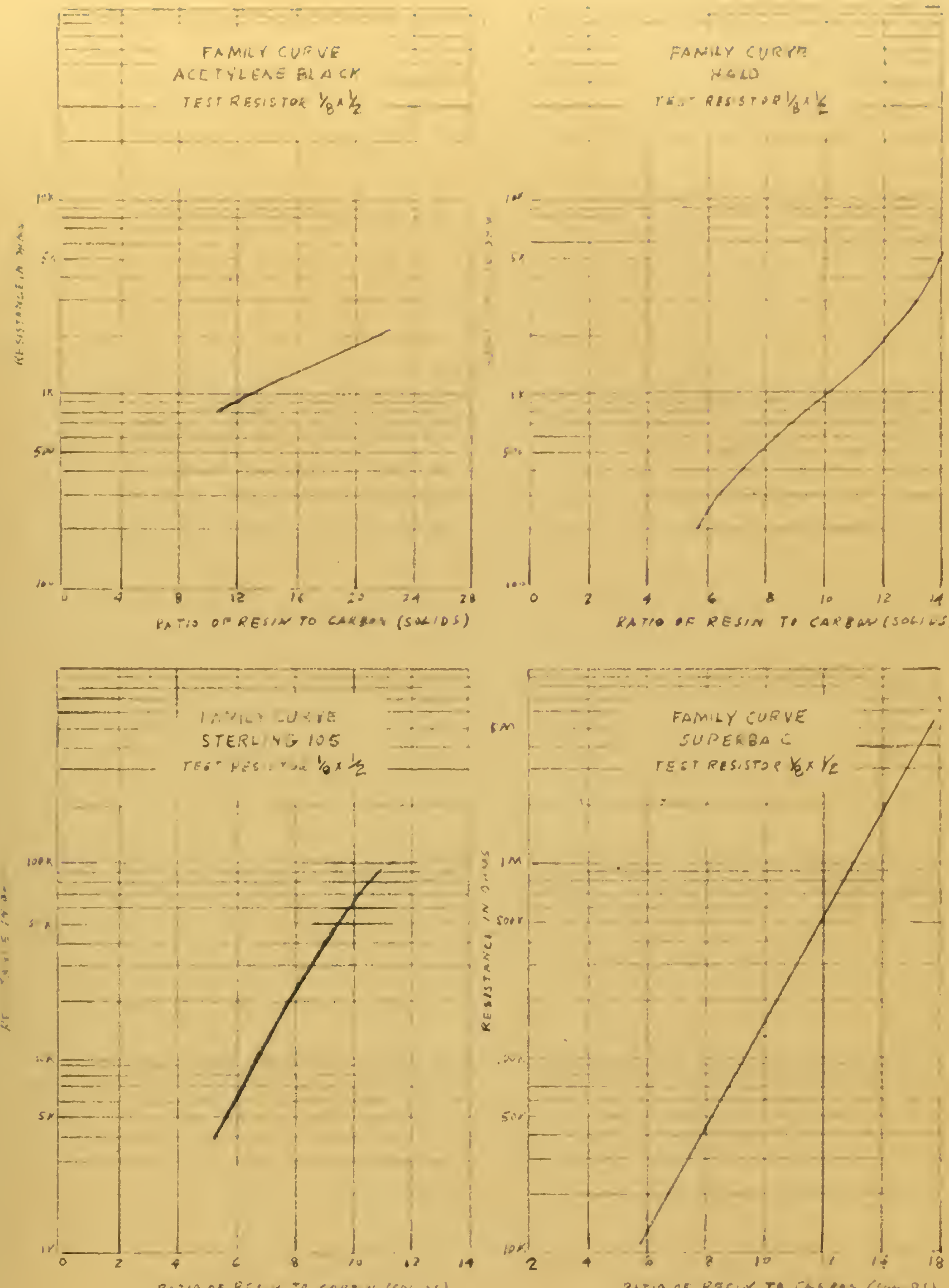
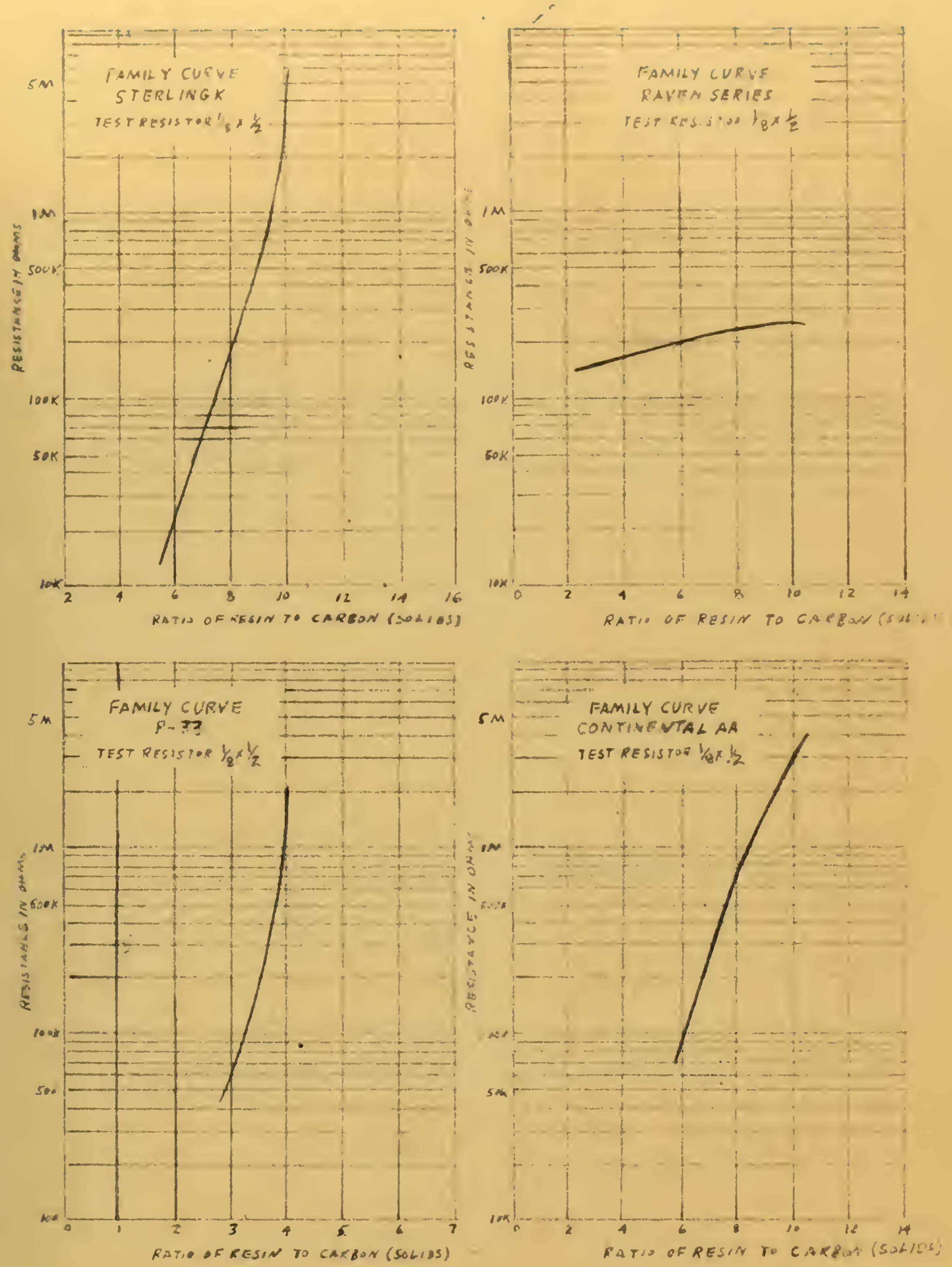

FAMILY CURVE
ACETYLENE BLACK
TEST RESISTOR 1/8 x 1/2
RATIO OF RESIN TO CARBON (SOLIDS)
FAMILY CURVE
TEST RESISTOR 1/8 x 1/2
RATIO OF RESIN TO CARBON (SOLIDS)
FAMILY CURVE
STERLING 105
RATIO OF RESIN TO CARBON (SOLIDS)
FAMILY CURVE
SUPERBA C
TEST RESISTOR 1/8 x 1/2
RESISTANCE IN OHMS
RATIO OF RESIN TO CARBON (SOLIDS)

Figure 5



FAMILY CURVE
STERLING K
TEST RESISTOR 1/8 x 1/2
RESISTANCE IN OHMS
RATIO OF RESIN TO CARBON (SOLIDS)
FAMILY CURVE
RAVEN SERIES
RESISTANCE IN OHMS
RATIO OF RESIN TO CARBON
FAMILY CURVE
P-33
TEST RESISTOR 1/8 x 1/2
RESISTANCE IN OHMS
RATIO OF RESIN TO CARBON (SOLIDS)
FAMILY CURVE
CONTINENTAL AA
TEST RESISTOR 1/8 x 1/2
RESISTANCE IN OHMS
RATIO OF RESIN TO CARBON (SOLIDS)

Figure 6

[redacted]

TABLE II

Carbon	Particle size in microns	Resin to carbon ratios: Max. Ratio	Resistance in ohms	Min. Ratio	Resistance in ohms	Temperature Coefficient JAN R-11 Characteristic
			ARTIFICIAL GRAPHITES			
Dag Dispersion 22	varies	6	770K	1	100	F
" " 47	"	5	91K	-	-	F
" " EC427	"	5	30K	2	780	F
Dag Ultra-fine	"	5	5K	-	-	-
			NATURAL GRAPHITES			
Dixon 200-09	5	10	72K	1	110	F
" 200-10	.2.5	6	6.6K	3	370	E
" 200-10F	2.5	5	6.3K	-	-	-
			CHANNEL BLACKS			
Continental AA	30 to 35	10	2.9M	4	6.4K	F
Halo Black	20	28	1.2M	6	1.2K	F
Raven 15	28	10	470K	6	200K	E
			FURNACE BLACKS A			
Statex A	50	10	300K	4	5K	E
Statex B	43	8	25K	-	-	F
Sterling 99	39	8	80K	-	-	E
" 105	32	14	140K	6	10K	E
			FURNACE BLACKS B			
Acetylene Black	43	18	1.6K	14	1.2K	-
P-33	150-200	4	1.3M	3	63K	-
Sterling K	43	14	185K	6	16K	E

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[illegible]

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TABLE III

Resistance in ohms	Max. Ambient temp. in °C	Preferred carbon	Ratio by weight resin to carbon
100	200	Dag 22	1 to 1
200	200	Dixon 200-09	2.5 to 1
300	200	"	3 to 1
500	200	"	4 to 1
800	200	Dag EC-427	2 to 1
1,000	200	Dag 22	2 to 1
1,500	200	Dixon 200-09	5 to 1
2,000	200	"	6 to 1
4,000	150	Excelsior Black	8 to 1
5,000	200	Statex A	4 to 1
5,000	150	Halo Black	8 to 1
6,000	200	Dixon 200-10F	5 to 1
7,000	150	Halo Black	9 to 1
10,000	200	Statex A	5 to 1
15,000	200	Sterling K	6 to 1
20,000	200	Statex A	6 to 1
30,000	200	Dag EC-427	5 to 1
35,000	200	Statex A	7 to 1
50,000	200	"	7.5 to 1
60,000	150	Halo Black	14 to 1
70,000	200	Statex A	8 to 1
100,000	200	"	8.5 to 1
130,000	150	Halo Black	15 to 1
140,000	200	Sterling 105	14 to 1
200,000	200	Statex A	9.5 to 1
300,000	150	Halo Black	22 to 1
500,000	150	Continental AA	7.5 to 1
800,000	150	"	8 to 1
1,000,000	150	Halo Black	26 to 1
2,000,000	150	Continental AA	9 to 1
3,000,000	150	"	10 to 1

[redacted]

The carbon for the particular resistance mixture chosen is calcined for three hours at 2250°F to remove the impurities. After the carbon has been permitted to cool it is mixed in the proper proportions with the silicone resin and the butyl cellusolve solvent. The ratio by weight of the nonsoluble particles to the soluble particles and the solvent is kept constant as the resin to carbon ratio is changed for different values of resistance. The purpose of this is to maintain the apparent viscosity of the spray mixtures the same.

Two typical mixtures for different values of resistance are given below to illustrate this principle.

Resistance:	500 ohms	100,000 ohms
Carbon:	Dixon 200-09 20 gm	Statex A 10 gm
Binder:	DC-996 Resin 160 gm	DC-996 Resin 180 gm
Thinner:	Toluene 120 gm	Toluene 110 gm
Solids:	20 gm of carbon plus 80 gm of resin = 100 gm	10 gm of carbon plus 90 gm of resin = 100 gm
Solubles:	80 gm of resin plus 120 gm of solvent added = 200 gm	90 gm of resin plus 120 gm of solvent added = 200 gm

The mixture is poured into a cylindrical jar which is revolved at 80 rpm for two to three weeks on a ball milling machine. Porcelain balls are placed in the milling jar with the mixture to insure complete emulsification. The one and one quarter inch wide asbestos tape is formed into an endless belt about nineteen feet long which is placed over motor driven rubber rollers in the resistor spray cabinet. The rubber rollers carry the tape past the spray gun opening in the cabinet at about thirty-eight feet per minute for thirty complete revolutions.

[illegible]

[illegible]

[illegible]

[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]

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The air operated spray gun containing the resistor mixture is motor driven in simple harmonic motion back and forth across in front of and about five inches away from the tape at about four-hundred oscillations per minute, overshooting about the width of the tape on either side. It is adjusted to spray about two and one half ounces of mixture at the tape during the thirty revolutions of the tape belt. The large number of thin coatings, the high speed of the tape, and the overshoot of the gun on either side of the tape are used to obtain as uniform a coating as possible. To further insure the tape to be used is uniform, only the center section which is cut into five narrow strips is used. The widths of the strips cut may be varied in ten mil steps to compensate for slight differences from the desired value of resistance resulting from a given mixture. The outer strips are normally made slightly wider than the center strip to compensate for small variations in resistance across the width of the tape, resulting from the method of spraying. Test strips are cut from each tape to use in determining the proper width of strips required before the entire tape is slit.

When the higher ratios of resin to carbon are used it is necessary to partially dry the tape between spray coatings. Heat lamps are installed in the cabinet to accomplish this during the spraying process. After the last coating has been sprayed and before the resistor tape is removed from the spray cabinet, polyethylene tape is rolled over the resistor coating to protect it from damage in handling and storage.

If desired, the tape may be stored for months under refrigeration in the uncured condition.

[redacted]

As the tape is applied to the module wafer the protective coating is stripped off and the tape is cut into individual one half inch long resistors. The tape remains tacky until cured so that no additional adhesive is required to attach the resistor to the face of the wafer. Silver electrodes painted on the face of the wafers provide conducting paths between the resistors and the proper riser wire notches. After it has been applied to the wafer, the resistor is cured for four hours at 300°C to polymerize the resin. Progressive assembling of resistors to a wafer is shown in figure (2).

The resistors are covered by a second tape which protects them from damage by solder flux during a later dip-soldering process to pretin the wafer notches. The protective tape is made in a spray process similar to that used for the tape resistor but using a silicone alkyd spray mixture. After curing, it is necessary to temperature cycle the resistor four or five times. The protective tape is cured during this temperature cycling of the resistor.

(b) Wire wound resistors have been made experimentally by winding the resistor in two sections on a special type wafer, the direction of winding being reversed between the two sections. It is planned to use "non-inductive" resistor wire in two different sizes to provide precision resistors covering the range of resistance from about one ohm to two megohms with a one per cent tolerance. Although time has not permitted this to have been accomplished yet, no difficulties appear to stand in the way when the need for such resistors arise. Several possible forms of these resistors are shown in figure (7).

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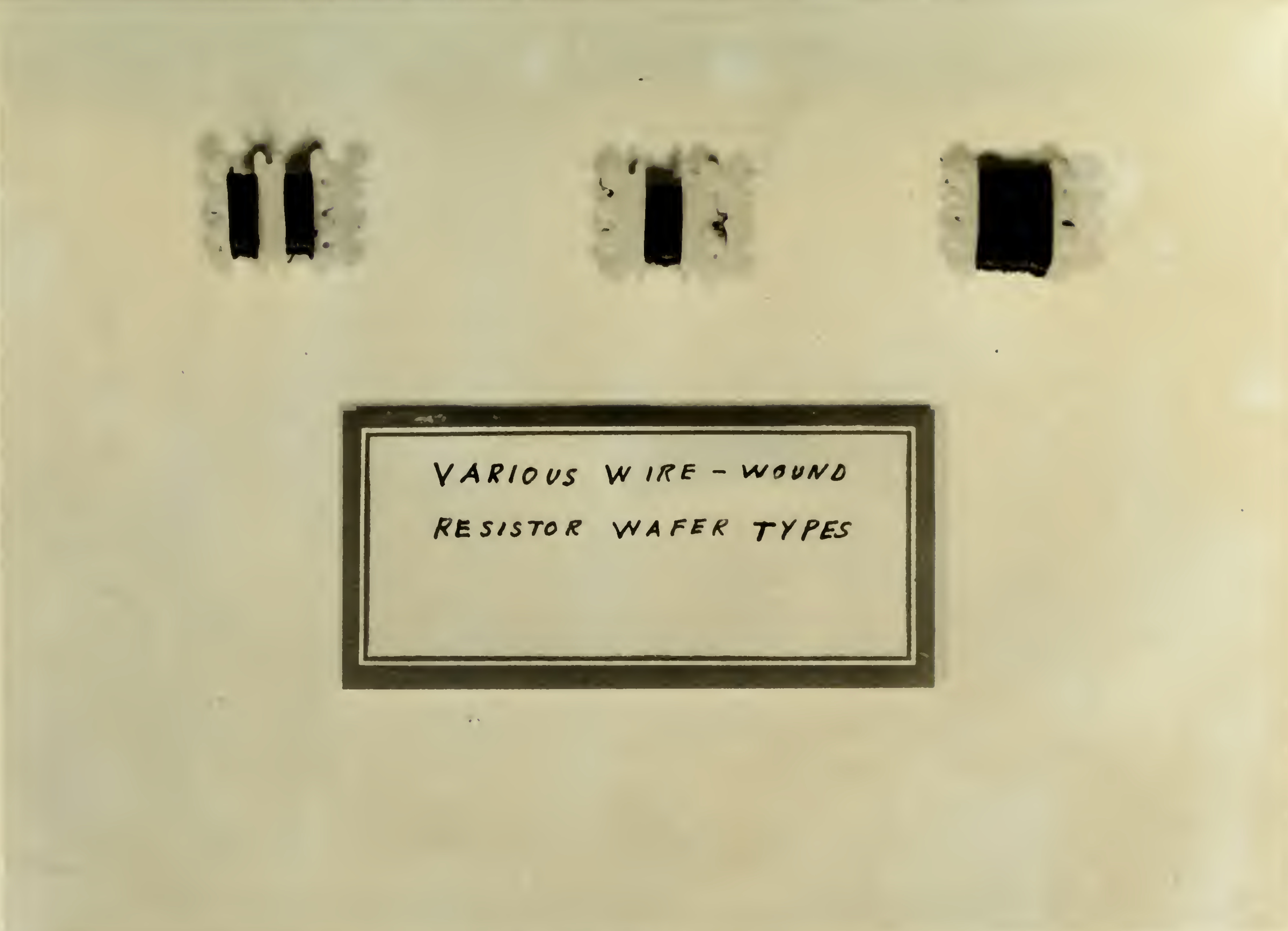

Figure 7

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(c) A small variable resistor has been mounted on a special type wafer with the shaft extending through a hole in the center of the wafer. Initial work has been limited to modification of an existing resistor rather than producing it. The components and an assembled resistor of this type are pictured in figure (8).

4. Inductances

Various techniques have been used to produce module size inductances, but no standard method has been adopted for incorporation into the production facility. Coils on the order of a few microhenries have been photo-etched on copper clad phenolic and mounted on module wafers for use in circuits being modulized. Bifilar coils having a coefficient of coupling as high as three-fourths have been made using similar techniques. Attempts have been made to produce inductances by silk-screening spiral coils directly upon the module wafer, but to date satisfactory results have not been obtained. Examples of these various types are illustrated in figure (9).

Inductances up to the order of sixteen millihenries have been obtained by winding a coil on a core secured between two wafers as shown in figure (10). Inductances have also been wound upon small spools, such as pictured in figure (9), which are cemented to the wafer. The smallest such spool used to date permits mounting up to five alongside each other upon one side of a wafer and sufficiently thin to permit placing a capacitor on the adjacent face of the next wafer. One such spool was used for winding an inductance of about one hundred eighty microhenries. Number forty teflon covered wire was used. An unloaded Q of thirty-one was obtained as determined with a

Figure 8

Modulized variable resistance.

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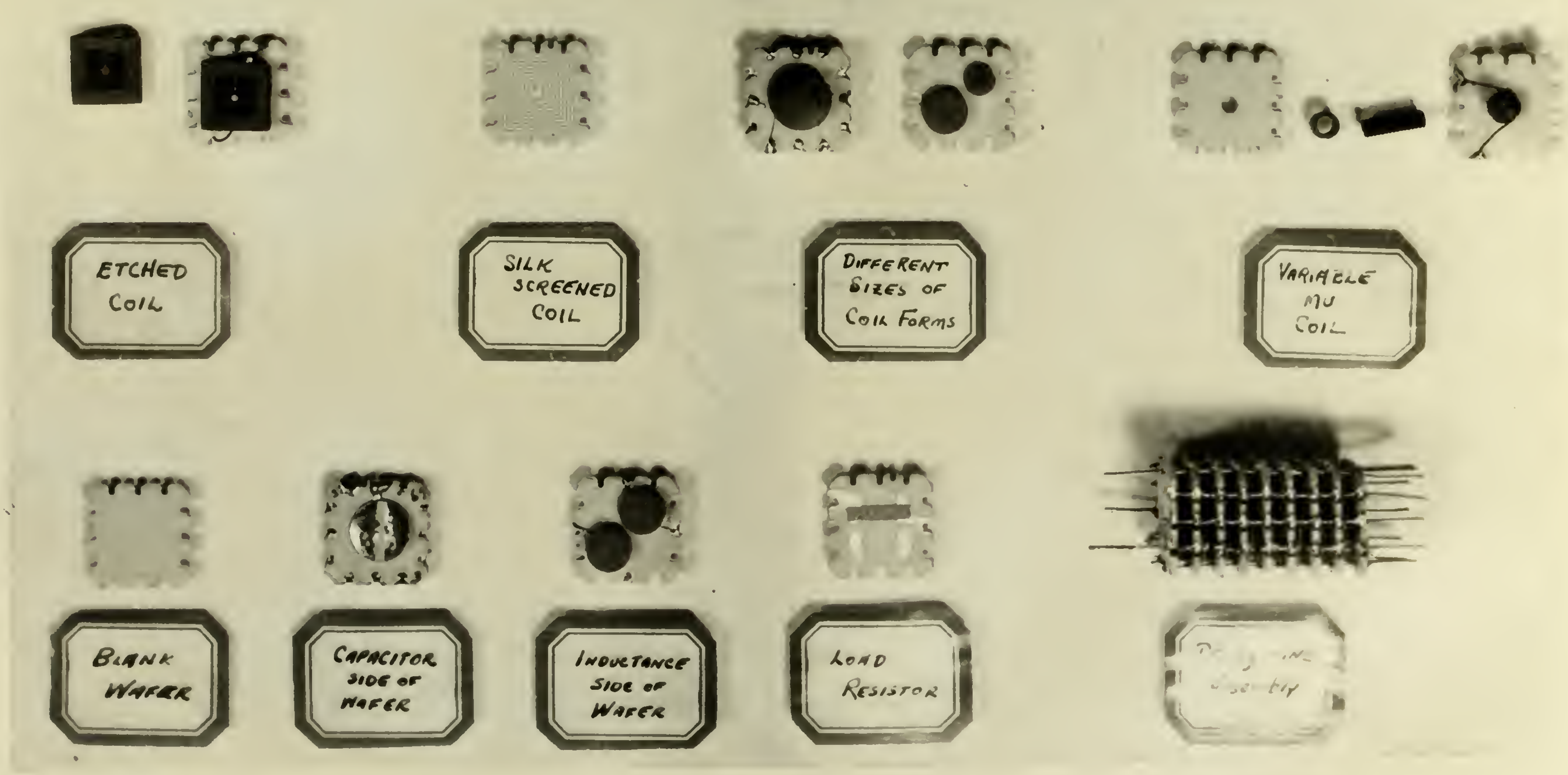

Figure 9

Bottom: Component parts and assembled delay line.

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Figure 10

Wound inductance coil forms.

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Q-meter. Lower Q values were obtained, however, in similar coils made with larger wire having a less satisfactory insulation.

Variable inductances have been obtained by using a rotatable disc to short out part of the turns of an etched coil, and by slug tuning of coils wound upon hollow forms. The slug-tuned inductance is mounted on a special wafer with a hole in the center through which a threaded slug can be screwed in and out of the threaded coil form. The slug-tuned coil is shown in figures (3) and (9).

5. Tube sockets

Both seven and nine pin miniature tube sockets have been standardized for use in the Tinkertoy system. The tube sockets are made of steatite in a process similar to that used for making the module wafers. The pin connectors of beryllium-copper extend out to the edge of the module wafer for soldering directly to the riser wires. The tube socket is center riveted to a special type wafer and is oriented so that one side which is flat always lies parallel to an edge of the module wafer. The steps in assembly of the tube socket to the wafer are illustrated in figure (1).

Some consideration has been given to inclusion of sub-miniature type tube sockets in the system, but for the present where sub-miniature tubes are used they are soldered into the circuit.

6. Conventional components

Large conventional components which cannot be eliminated from the circuit such as power transformers, large tuning capacitors, high wattage resistors, and mechanical parts are grouped together in one section if possible. Smaller conventional components are placed in non-standard

modules by eliminating one or more wafers, if necessary, to make room for them. These components may be secured to a wafer, suspended between wafers, or suspended between riser wires. Certain components may be potted in module size blocks for fitting between the baseplates with the standard modules.

7. Tinkertoy modules

Each module normally contains the tube and components associated with one stage of the circuit being produced. The component wafers are assembled in parallel stacks with at least one-eighth of an inch separation between wafers. Size number twenty tinned copper riser wires are soldered into the wafer notches to provide mechanical rigidity to the module and to provide electrical connection between the circuit components on the several wafers and to the top and bottom baseplates. The normal module has been standardized to have five wafers although the pilot production line has been designed to produce six-wafer modules, if desired. With moderate changes in the assembling machines larger modules could be produced. Riser wires not needed for mechanical strength or electrical connections may be cut at the end of the modules or between wafers. In general, at least one riser wire on each side of the module should be secured to the baseplates at the top and bottom to provide mechanical rigidity even when not necessary for making electrical connection.

8. Baseplates

The modules containing the various stages of a functional subassembly are assembled between top and bottom baseplates. The baseplates provide mechanical support and through the conducting circuit etched upon them

provide electrical connections between the individual modules and to circuits external to the plate assembly. The Tinkertoy system at present does not extend beyond the production of these plate assemblies. They may be seen in various forms in the pictures of equipment included in chapter IV.

The baseplates are made from sheets of one-sixteenth inch thick XXXP Phenolic resin insulator to which two and seven-tenths mils thick copper foil is bonded on one or both sides. The cheaper single clad sheets are normally used for making the baseplates, but for special purposes double clad sheets may be used.

The etching process used at Sanders Associates in making relatively few plates of one kind differs somewhat from the process to be used in the pilot production line where large numbers of one design plate are to be made. The process used by Sanders Associates will be described with the major differences in the two methods being indicated.

A double size drawing of the baseplate design is made and photographed, reducing the size back to normal in photographing for producing a uniform negative to be used in exposing the baseplate. The copper-clad surface of the phenolic is scoured to remove all copper oxides. A uniform coating of cold top enamel which is sensitive to ultraviolet light is then spread over the copper surface by spinning the baseplate material at one hundred fifty revolutions per minute while the enamel is being poured over it. The coating is dried by infra red heat lamps placed over the spinning baseplate. Then a second coat is applied in the same manner. The negative is held flat against the coated copper

surface while it is being exposed for about three minutes under an ultra-violet light. The exposed baseplate is placed in a cold top enamel developer for about thirty seconds and then washed in lukewarm water to remove the water soluble unexposed areas of enamel. The remaining exposed enamel is then set by drying under an infra red lamp.

The method to be used in the pilot production line differs from the above in that the negative is used to produce a "silk-screen" for stenciling the acid resist patterns on the baseplate material. After the negative has been developed and the exposed emulsion has been washed away, the negative is placed over a fine mesh non-corrosive metal screen and the remaining soft emulsion is forced into the screen openings in the areas where the pattern was not exposed. The emulsion is then fixed and the film is peeled away, leaving the emulsion in the screen except for where the exposed pattern left no emulsion on the negative to be transferred to the screen. The silk-screen pattern may now be used for stenciling any number of baseplates with an acid resisting coating.

The baseplates with the desired conducting pattern protected from the etching acid by the acid-resist coating is placed above an etching solution of ferric chloride in a rubber lined tank. Compressed air is used to bubble the etching solution up on the plates for etching away the unprotected copper foil. The etching process requires a period of from five to fifteen minutes, depending upon the strength of solution used. After the baseplate is etched, it is rinsed to remove the acid and then the acid-resist is removed with steel wool.

The etched baseplate is completed by cutting to the final shape,

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punching the necessary openings for the tube sockets, and drilling holes for the riser wires which are to extend through the baseplate. The conducting pattern is pretinned by dip-soldering. The modules are then assembled to the baseplates and secured in place by dip-soldering the riser wires to the conducting patterns.

A protective insulating coating such as insl-X U-95 is brushed or sprayed over the baseplates to provide protection from dirt and corrosion, and to provide insulation between the conductors on the baseplates. The remarkable advantages of this coating have been shown in tests. In one test leakage between conductors on a coated plate was not detectable down to a minimum spacing of thirteen and one-half mils, but on uncoated plates leakage was noted for spacings below forty-six mils and breakdown occurred in one case with a spacing of sixteen and one-half mils. In these tests, run under ambient room conditions, a maximum voltage of one thousand volts was used.

Other tests, conducted after the test plates had been immersed in salt water for six hours, showed no measurable leakage or breakdowns with coated plates. The breakdown voltage between conductors on uncoated plates varied from nine hundred volts with a seventy mil spacing to five hundred fifty volts with a twenty mil spacing.

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III. PRODUCTION LINE

The pilot production line for evaluation of the Tinkertoy system of mechanized construction of electronic equipment is at this writing in the final stages of adjustment of the machines. It has been designed to be sufficiently large for evaluation of the system of construction on the basis of production quantities. After completion of the evaluation and any modifications shown by the tests to be necessary have been made, the pilot line may be rapidly expanded to full scale production by the duplication of certain machines which do not have the capacity required for the plant to operate at full capacity of all machines.

At full capacity the pilot line is expected to produce at the rate of one thousand modules per hour. In terms of the first equipment to be modulized this will amount to six or seven thousand equipments per month. The pilot line is housed in a one-story building and only occupies about fifteen thousand square feet of floor space. All of the machines are small and of such a type that they may be mass produced if the need should arise. Where possible, machines which are already in production have been used, usually with some modification.

The line has been carefully designed with definite breaks in the machine process to provide maximum flexibility in operation. After each major process the components are manually transferred to the next step with varying periods of storage in between as desired. This prevents the possible breakdown, maintenance, or changing to a new setup in one machine from stopping the entire line. With each machine independent of

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the immediate output of the machines preceding it great freedom in scheduling is permitted.

At the completion of each major process automatic physical or electrical testing of the components is performed to eliminate defective components as soon as possible. Towards the end of the line where the number of components involved becomes larger it is desired to have very few rejects both to save in the materials being discarded but most important to save the production capacity from being wasted.

The assembly machines are designed to automatically shut down when jams occur or the supply of any component is exhausted. The testers may be set to stop if a certain number of successive components are rejected.

The machines are extremely flexible in the ease with which new circuits may be set up for production. The major advantage of the system selected is that the machines always handle the same physical components. To change to a new circuit it is only necessary to change the easily made silk-screens in the metallizing machines, the comparator heads in the resistor and capacitor value checkers, and the punched cards in the various testers. Of course, it is necessary to use the new correct dielectric constant capacitor bodies, the new correct values of resistor tape, and the correct type tube socket. However, as has been previously pointed out, the line may continue production of other components while each machine in its turn is being converted and started on production of the new circuit. The necessary silk screens, punch cards, capacitor bodies, and tape resistors may be prepared well in advance so that the machines need be stopped for a minimum of time to complete the change.

[redacted]

The processes involved in producing the components have been described in the preceding chapter so that this chapter may be devoted to following the complete manufacturing process and describing the machines themselves. A flow diagram of the pilot production line is given in figure (11).

The materials as received are primarily bulk or slightly machined materials available in ample quantities. It is not planned to provide large storage facilities for these materials in the pilot production plant.

The bulk steatite or talc for making the wafers and tube sockets is mixed with water in conventional commercial type mixers such as are used in bakeries. The water is pressed out of the thoroughly mixed steatite, leaving it in large cakes which are then granulated to corn-meal size particles. The granulated steatite is hopper fed to a die-press which compacts it into the desired shape. From the die-press the wafers or tube sockets slide down a chute onto carrier plates which are manually transferred and stacked upon trolley cars of an endless belt oven where they are fired at 2300°F for eight hours.

Similar machines are provided in the ceramic facility for mixing, forming, and curing the ceramic capacitor bodies except that the machines are all of a smaller size.

After being fired, the different ceramic parts are manually transferred to gagers where the physical dimensions are checked and those parts not within the set tolerances are discarded. The gagers are fed by Syntron bowl type feeders which are similarly used throughout the

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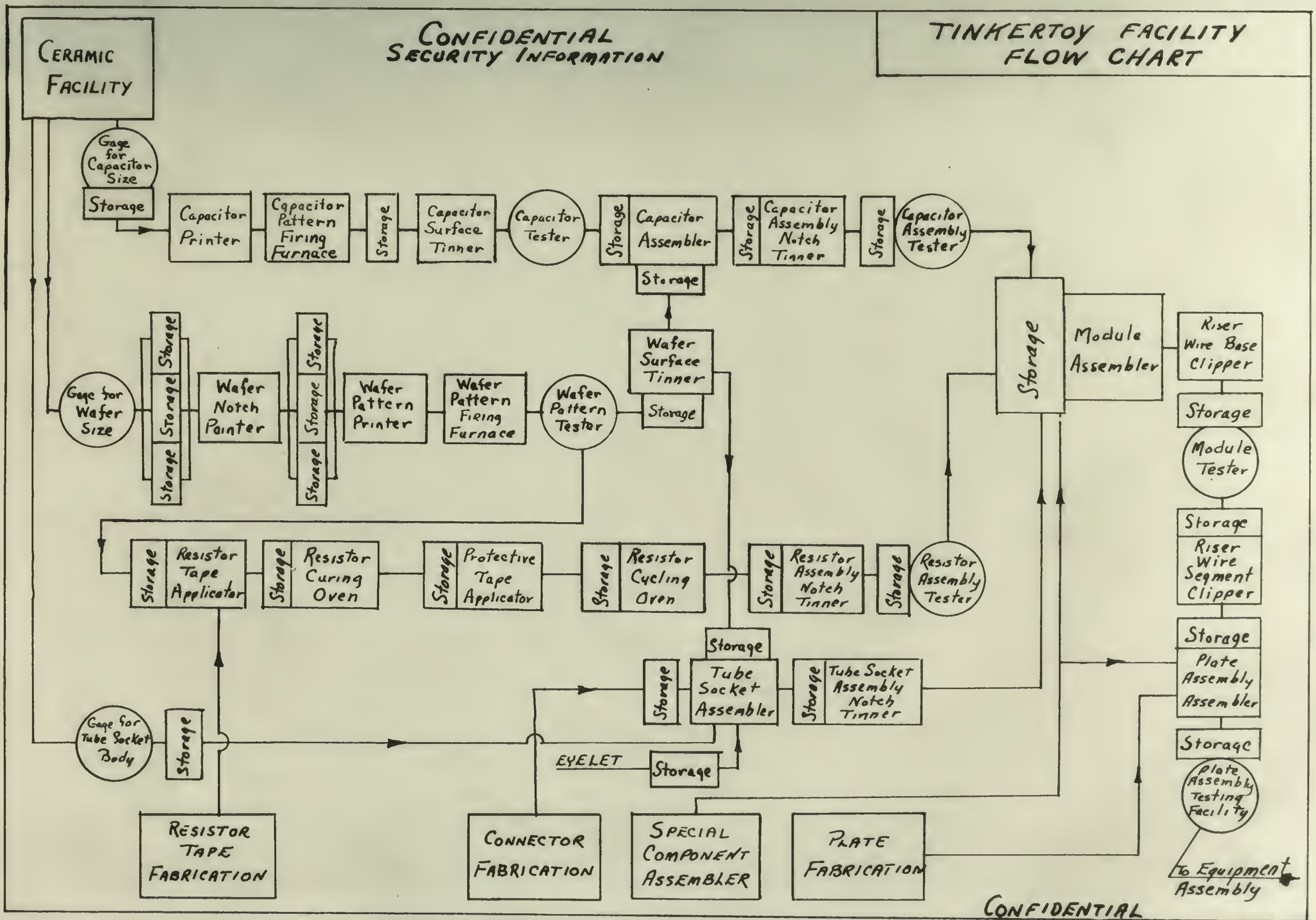

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TINKERTOY FACILITY FLOW CHART
CERAMIC FACILITY
Gage for Capacitor Size
Storage
Capacitor Printer
Capacitor Pattern Firing Furnace
Storage
Capacitor Surface Tinner
Capacitor Tester
Storage
Capacitor Assembler
Storage
Capacitor Assembly Notch Tinner
Storage
Capacitor Assembly Tester
Storage
Gage for Wafer Size
Storage
Storage
Storage
Wafer Notch Painter
Storage
Storage
Storage
Wafer Pattern Printer
Wafer Pattern Firing Furnace
Wafer Pattern Tester
Storage
Wafer Surface Tinner
Storage
Module Assembler
Riser Wire Base Clipper
Storage
Module Tester
Storage
Riser Wire Segment Clipper
Storage
Resistor Tape Applicator
Storage
Resistor Curing Oven
Storage
Protective Tape Applicator
Storage
Resistor Cycling Oven
Storage
Resistor Assembly Notch Tinner
Storage
Resistor Assembly Tester
Storage
Plate Assembly Assembler
Storage
Plate Assembly Testing Facility
Gage for Tube Socket Body
Storage
Storage
Storage
Tube Socket Assembler
Storage
Tube Socket Assembly Notch Tinner
EYELET
Storage
RESISTOR TAPE FABRICATION
CONNECTOR FABRICATION
SPECIAL COMPONENT ASSEMBLER
PLATE FABRICATION
To Equipment Assembly
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Figure 11

[redacted]

pilot facility. The parts are placed in the feeder bowl which is vibrated in such a manner as to cause objects to climb up a spiral ledge around the inside wall of the bowl. The bowl feeder is shown in several of the following pictures. The objects are discharged from the bowl down a chute to the gager. The wafer gager with the feeder is shown in figure(12). A close up of the final wafer gaging wheels are shown in figure (13). The parts which satisfactorily pass through the measurement gager are discharged to a small portable bin which is used for temporary storage and for carrying the parts to the next process.

Following the wafers through the production line, they are manually transferred to the feeder for the notch painter. In the notch painter they are carried by a continuous chain carrier through four sets of silicone-rubber paint applicator wheels, pictures of which are shown in figures (14) and (15). The three discs in each set of wheels run in a reservoir containing silver conducting paint. The paint is transferred to the wafer notches as the wafers are carried through the paint wheels. The five to ten mil coating of paint thus applied to the notches is dried sufficiently to permit handling the wafers by passing them under heat lamps before being discharged to the portable transfer bin. The notch painter is capable of processing a maximum of six thousand wafers per hour.

The wafers are manually transferred to one of the six channels of the wafer pattern printer. Each channel is fed by a bowl feeder which has been modified by the addition of an indexing device mounted on top the bowl. The indexing mechanism consists of a series of eight gates

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Figure 12

Wafer gager, Vibratory bowl feeder shown with feed chute and wheels for gaging size and thickness of wafers.

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Figure 13
Wafer gager. Close-up showing wheels that reject oversize and that reject undersize wafers.

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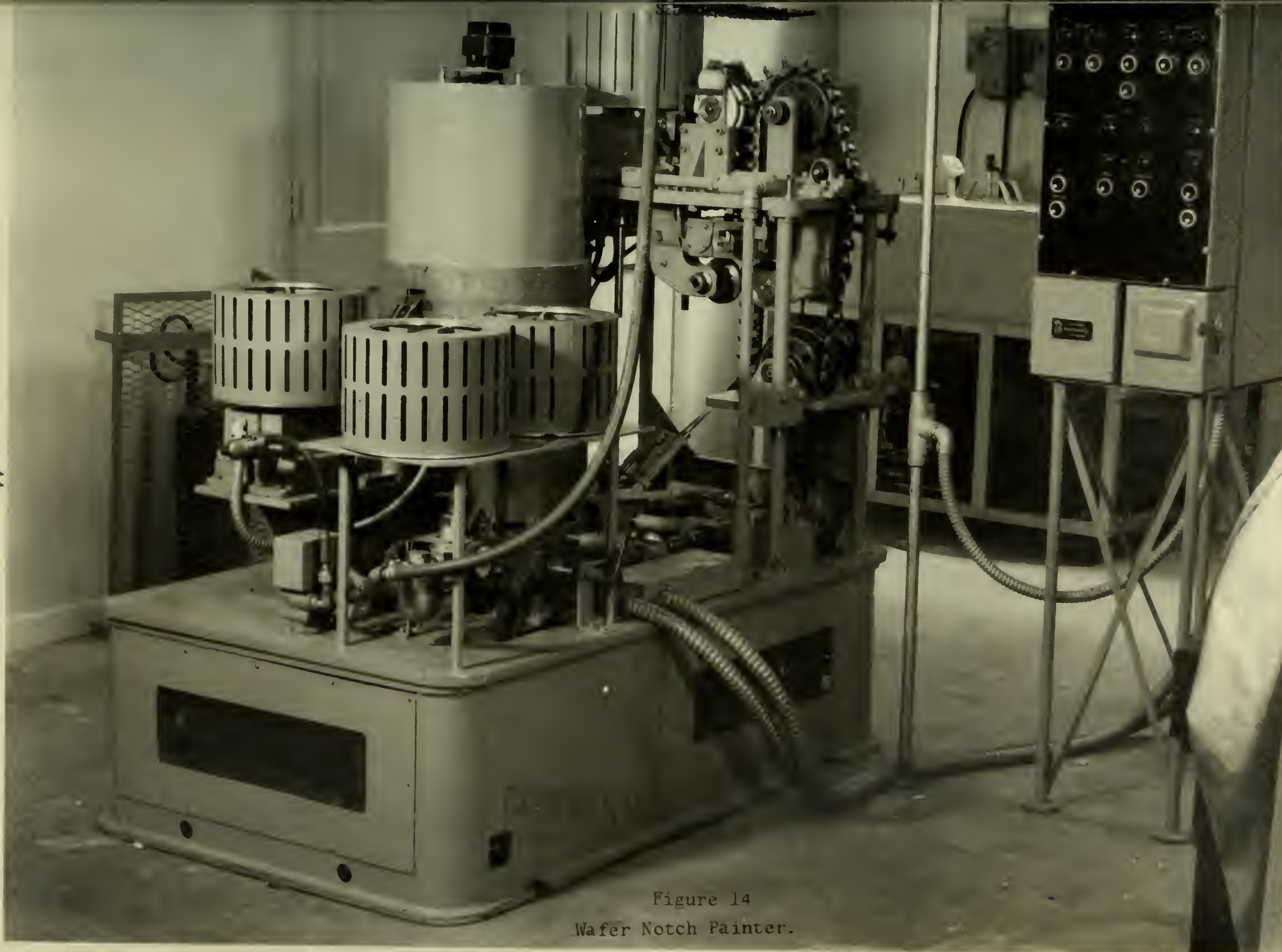

Figure 14
Wafer Notch Painter.

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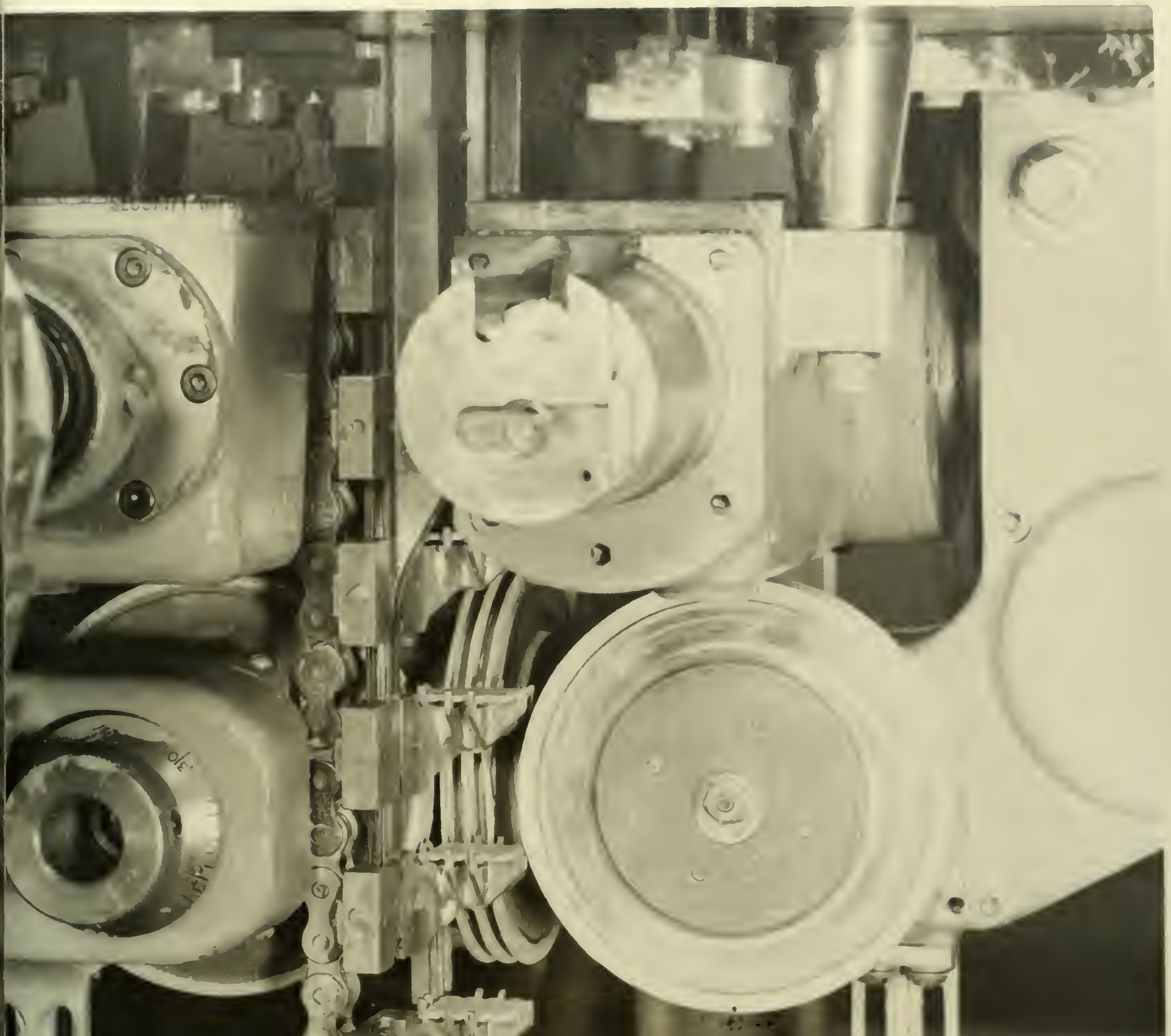

Figure 15

Wafer Notch Painter. Showing wafers in position for painting notches.

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which will permit the wafer to pass to the discharge chute only if the index notch of the wafer coincides in position with the location of the index pin at the top of each gate. The wafer standing nearly vertical and resting on one edge climbs the curved inclines containing the exit gates. After failure to pass through one exit gate, the wafer is tumbled through ninety degrees on to the incline for the next gate. If it does not pass through any index gate because of failure to be tumbled through ninety degrees one time, the wafer is returned to the feeder bowl to start over. The feed arrangement for the six channel pattern printer is pictured in figure (16).

The properly indexed wafers are carried through "silk-screen" patterns in the printer head shown in figures (16) and (17) where a squeegee is used to force silver paint through the screens on to the wafers, stenciling them with the proper patterns for the particular channel.

The silvered wafers are carried on through an endless belt oven where the silver is cured. The arrangement for transferring the wafers to the endless belt of the oven may be seen in figure (18). An automatic six channel pattern checker, shown in figure (19), makes an electrical continuity check between the notches of all wafers as they leave the oven to insure that they are properly painted. The pattern checker is controlled by punch cards inserted in the six channels of the checker. Defective wafers are discarded and the good wafers are discharged into portable bins for temporary storage or for immediate transfer to the next process. The punch cards accompany the bins of wafers through the

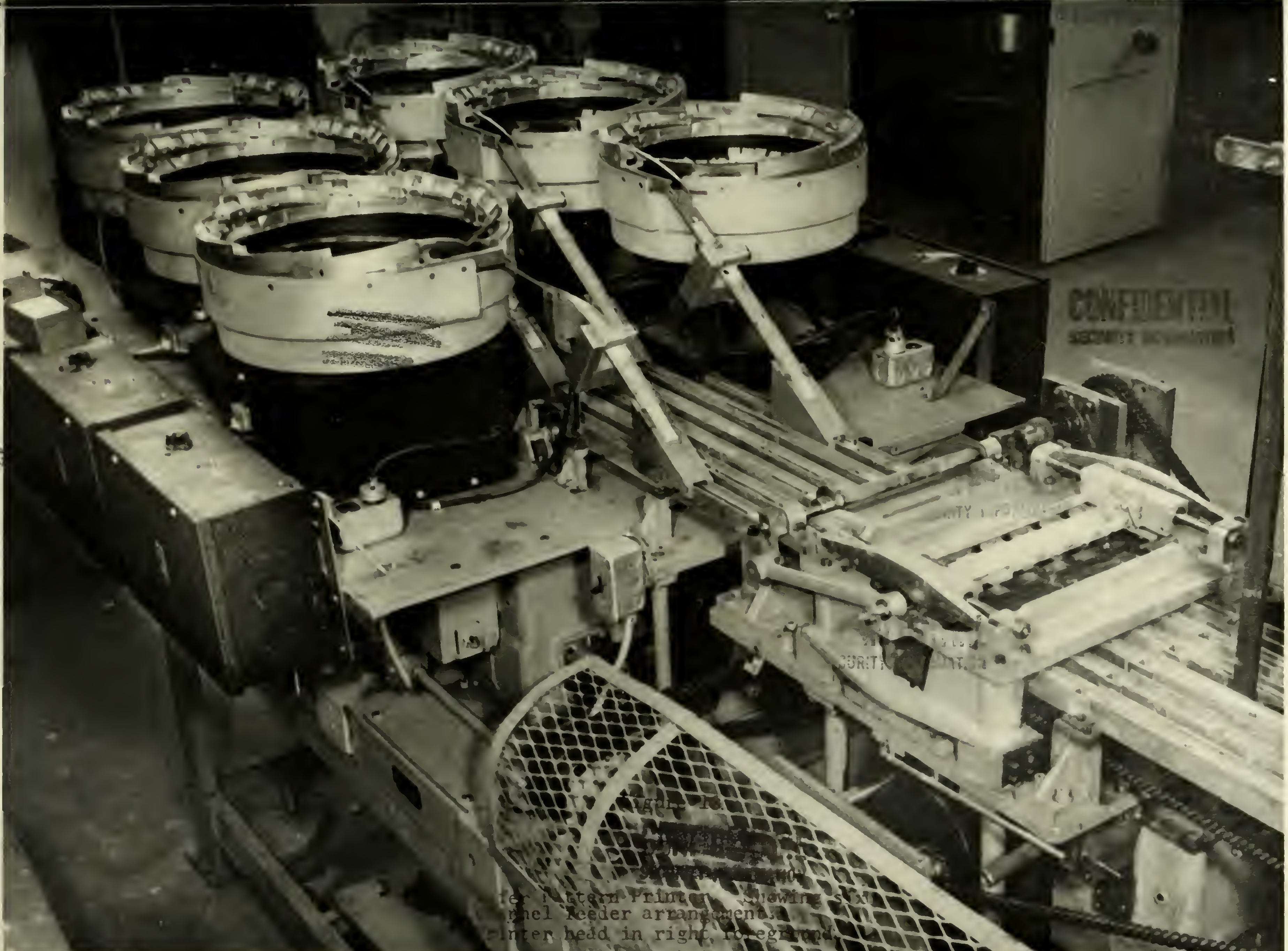

Figure 13

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...ter Pattern Printer, showing six ...nnel feeder arrangement. Printer head in right foreground.

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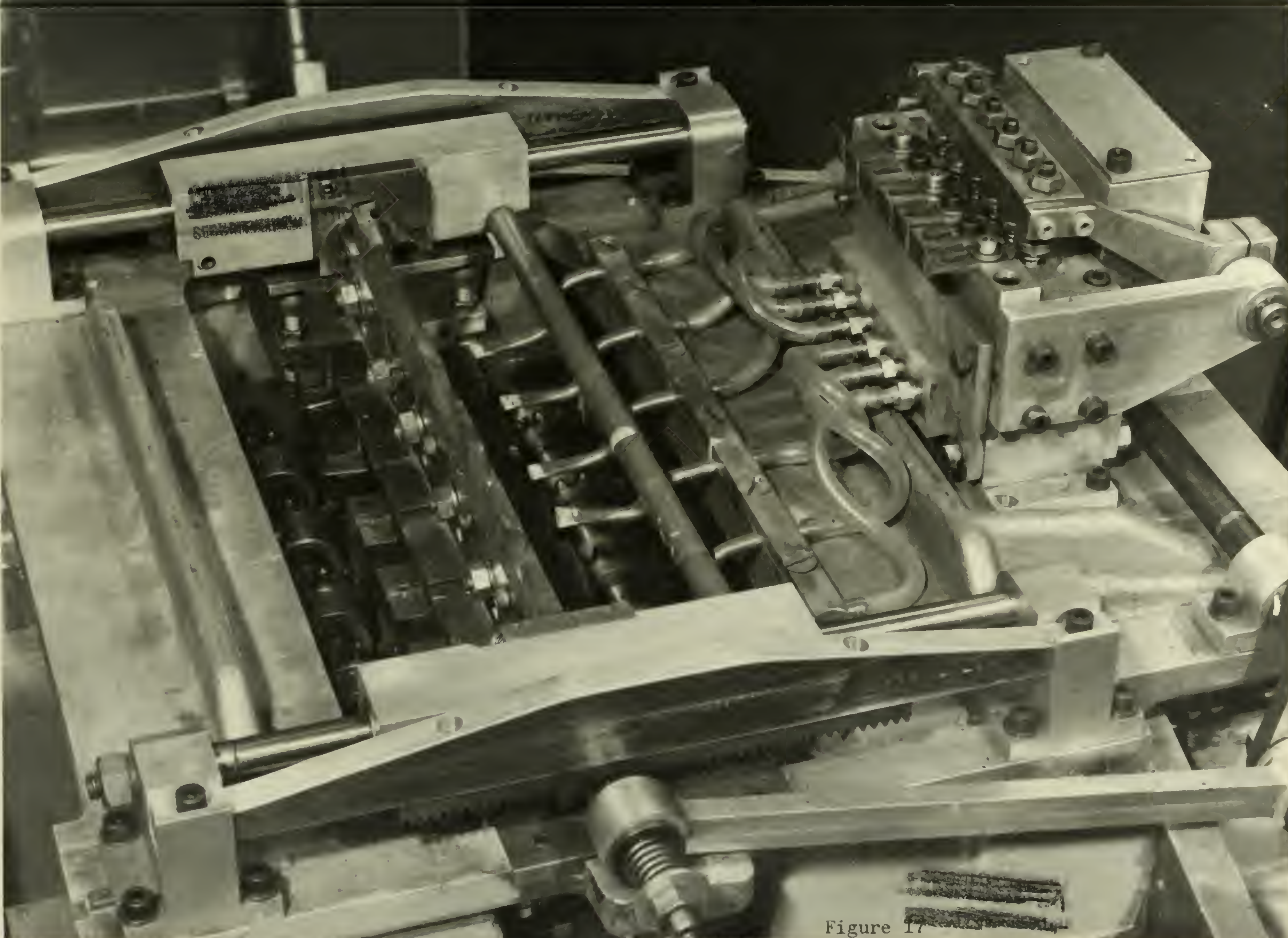

Figure 17

Wafer Pattern Printer. Close-up of printer head.

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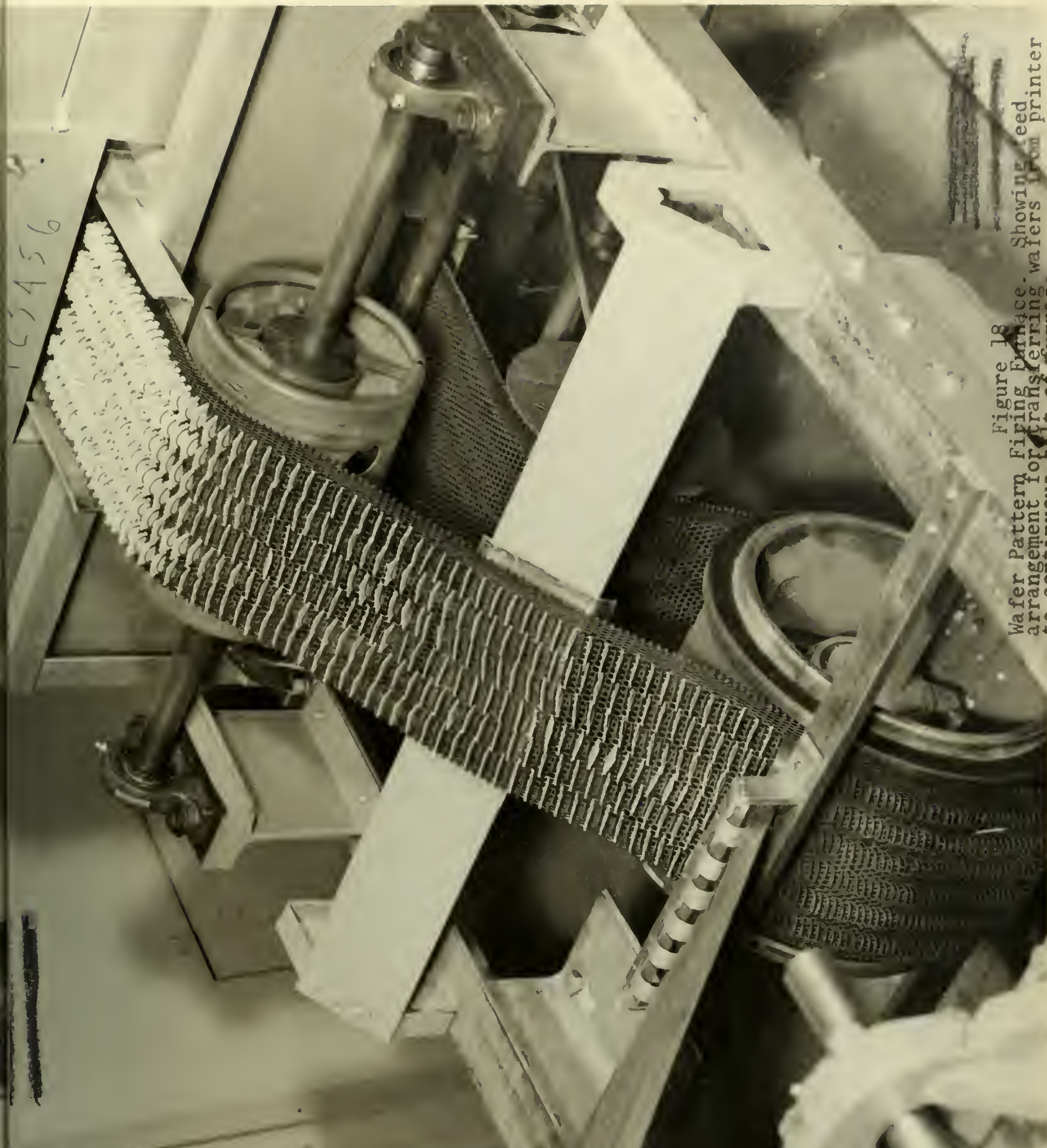

Figure 18
Wafer Pattern Firing Furnace. Showing feed arrangement for transferring wafers from printer to continuous belt of furnace.

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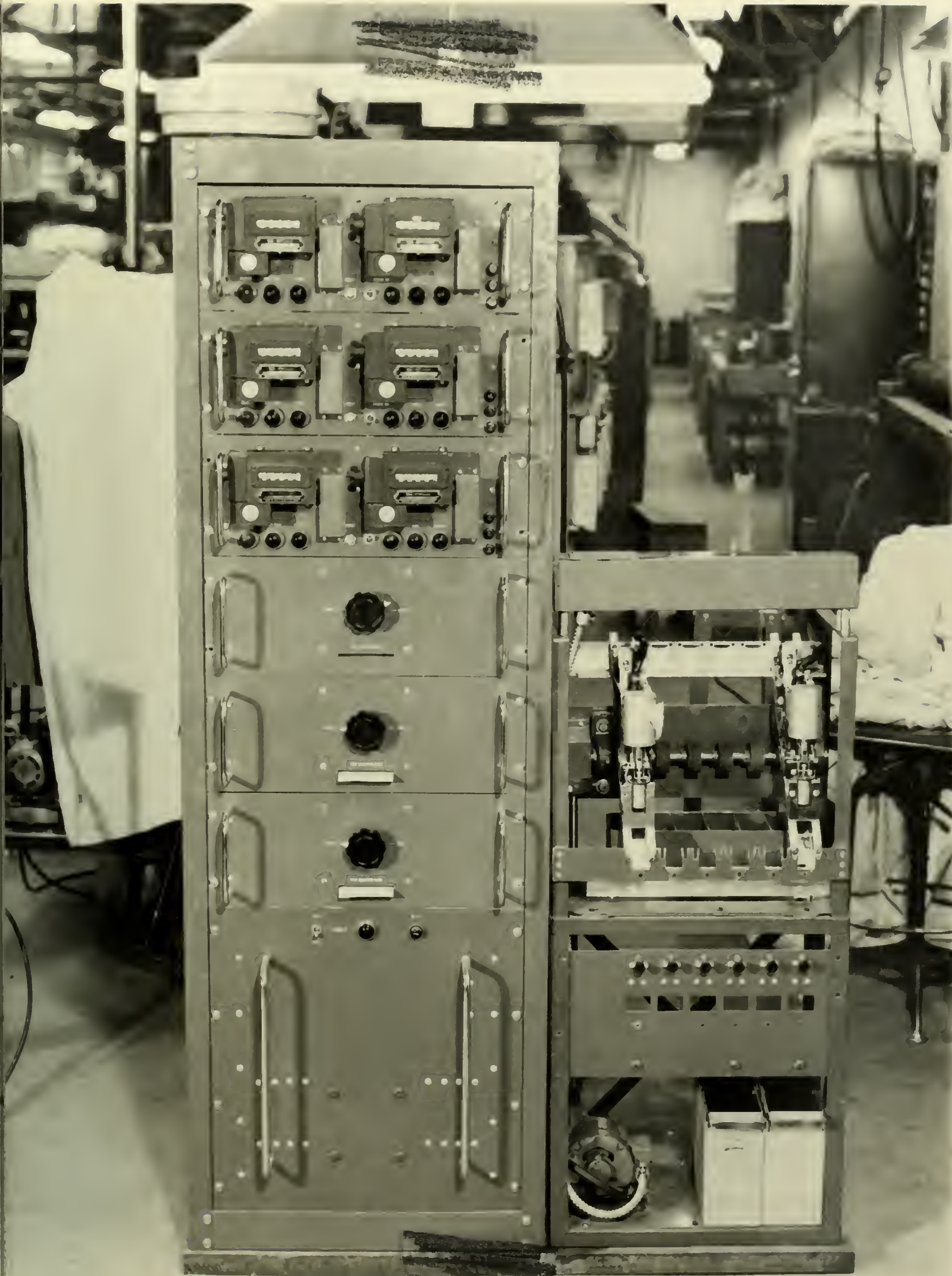

Figure 19
Wafer Pattern Tester.

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production line to the module assembler. If too many successive wafers, as determined by a setting on the checker, are discarded the pattern printer will be automatically stopped.

The capacitor discs are carried manually from the dimension checker in the ceramic facility to the capacitor disc printer where the proper size electrodes for the value of capacitance desired is silk-screened on in silver paint. The capacitors then are carried through an endless belt oven where the silver is cured. The fingers for carrying the capacitor discs through the printer are shown in figure (20), and the printer head is shown in figure (21).

The capacitors and the wafers upon which the capacitors are to be mounted are pretinned by dip-soldering in modified doughnut making type machines. The dipping machine for pretinning capacitors is shown in figure (22). The pretinned wafers are index fed to the capacitor assembler machine which places and clamps the capacitors on the wafers in the proper relationship. The parts are successively added to the assembly as it is carried in steps to the various stations by the carriers shown in figure (23). After all parts have been assembled the carrier moves under an inductance heating coil, which comes down around the assembly, as shown in figure (24), and heats the tinning solder to the melting point, soldering the parts together. Narrow silver ribbons for connecting the outside plates of the capacitors to the wafer notches are then soldered into place.

The tape resistors are produced in a spray cabinet similar to the one previously described. It is planned, however, to build a spray

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Figure 20

Capacitor Disc Printer. Showing manner of holding discs in the fingers.

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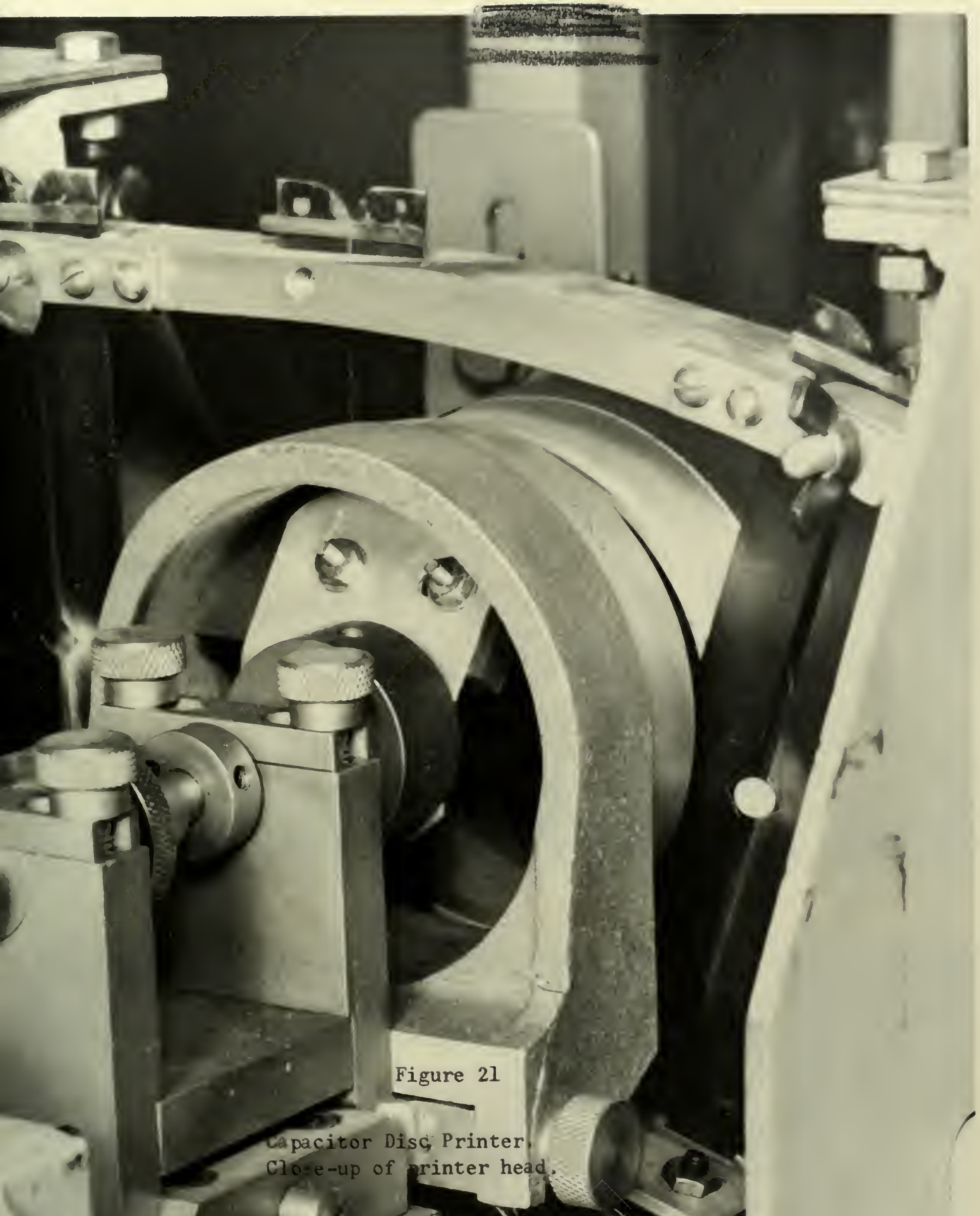

Figure 21

Capacitor Disc Printer.
Close-up of printer head.

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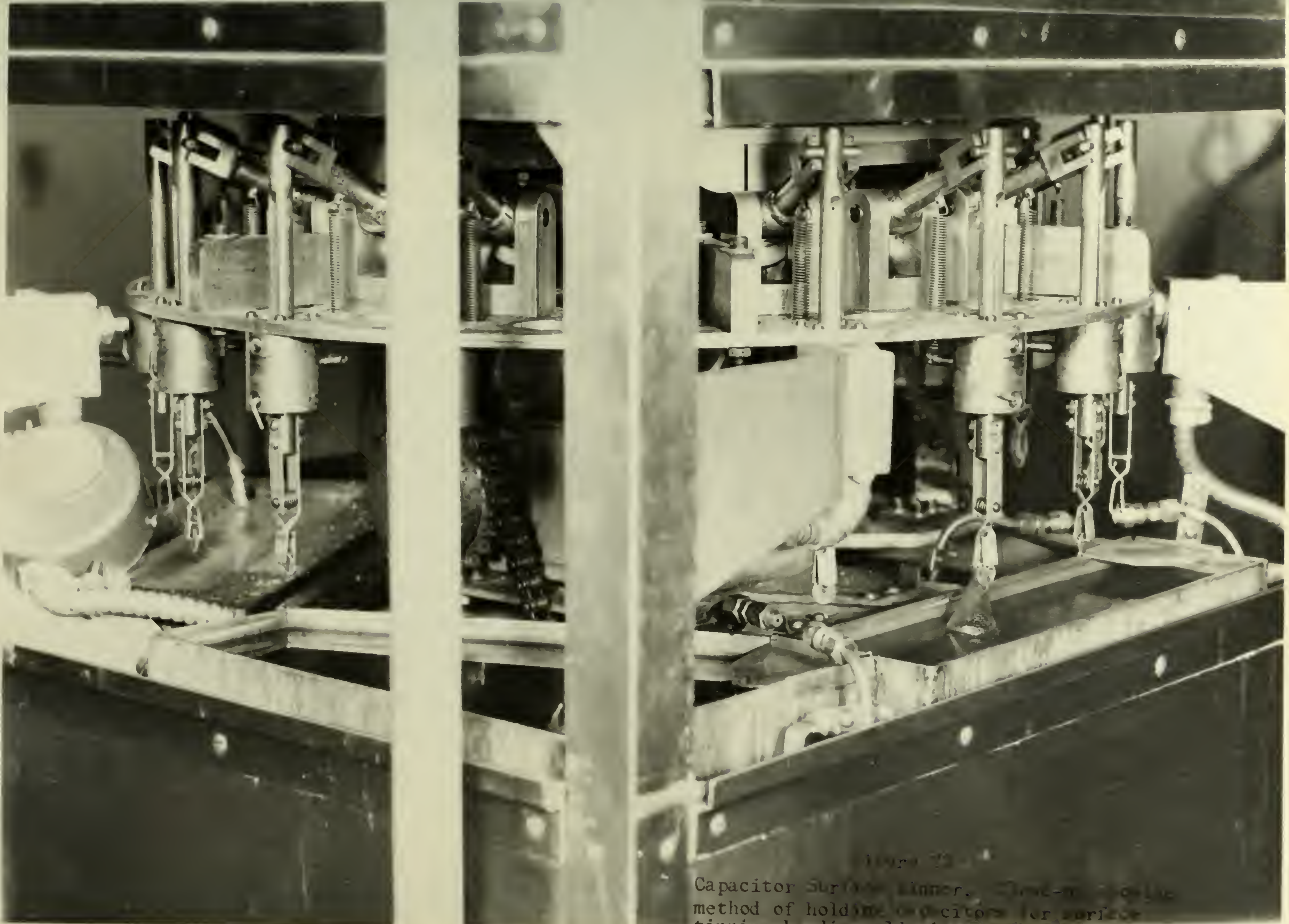

Figure [illegible]

Capacitor Surface Tinner. Close-up showing method of holding capacitors for surface tinning by dip-soldering.

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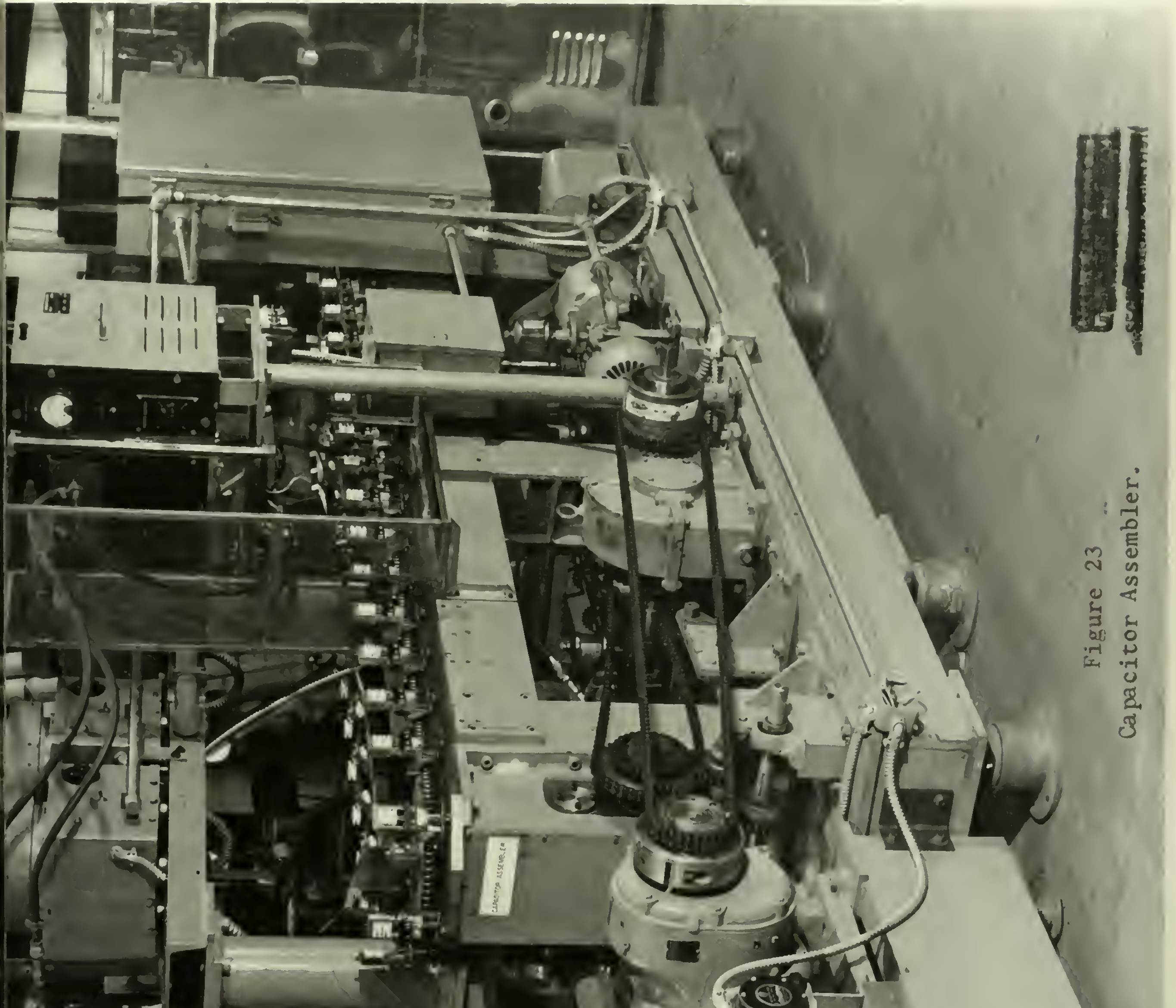

Figure 23
Capacitor Assembler.

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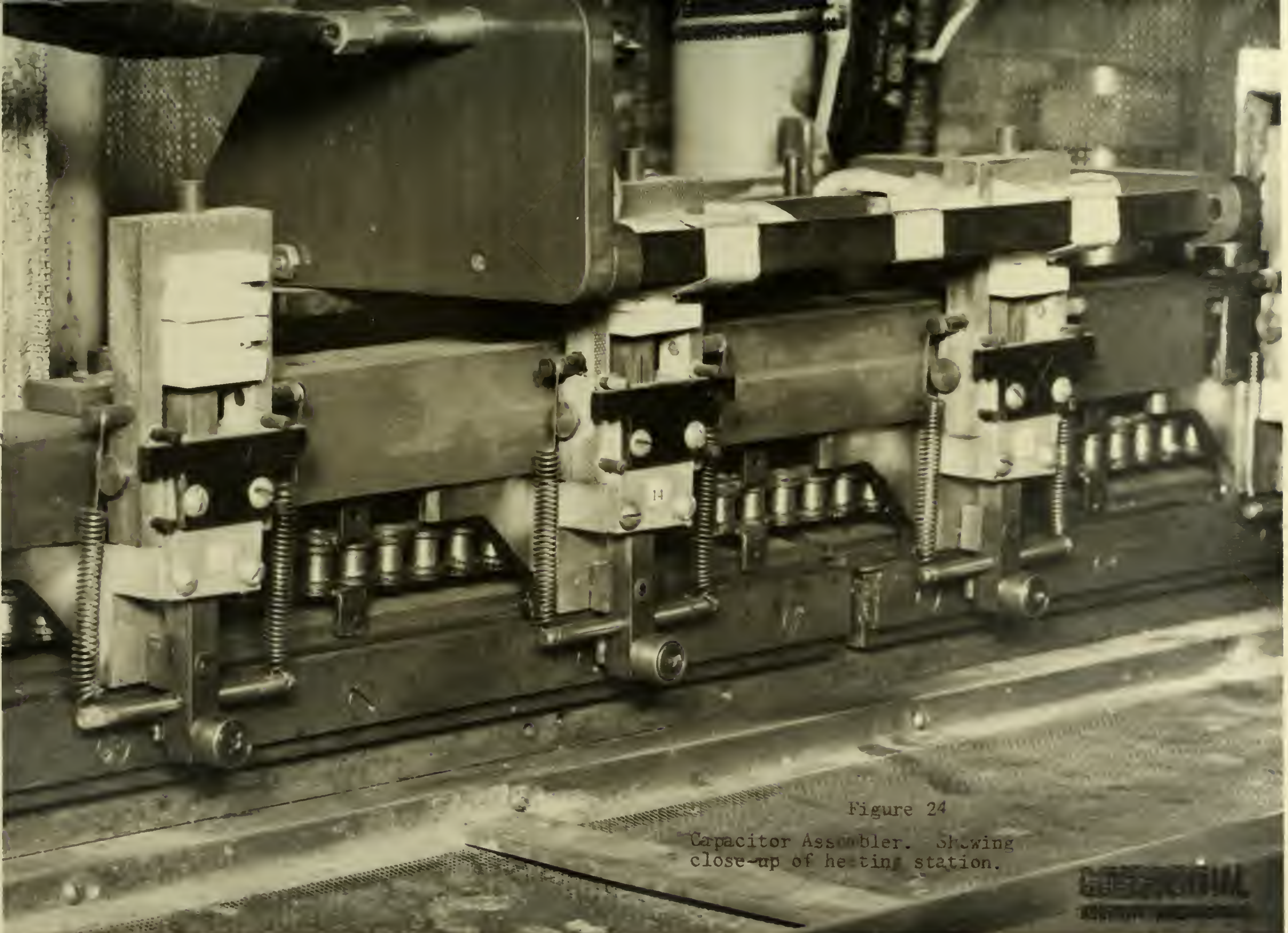

Figure 24

Capacitor Assembler. Showing close-up of heating station.

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cabinet which will handle much greater lengths of tape although the present spray facility should be adequate for the pilot production facility.

Rolls of the proper values of resistance tape for the circuit being manufactured are threaded in the tape applicator, shown in figure (25). The proper channel of wafers are index fed to the tape applicator machine where the wafers pass in intermittent steps to between the tape applicator heads. The narrow strips of resistor tape are fed down to the applicator heads and the polyvinyl protective tape is pulled off. The tape is cut into one half inch length resistors and placed on the wafers either parallel or perpendicular to each other on the opposite sides of the wafer. Up to two resistors may be placed on each side of a wafer. The wafer then passes between press heads which move in to press the tape firmly against the wafer.

After leaving the tape applicator the wafers are carried through an endless belt oven where they are cured for four hours at 300°C.

When the production line has been modified to include the new silicone alkyd protective tape, it will be applied over the resistor tape by a second tape applicator. The resistor wafers are then carried by an endless belt through a series of four short ovens to stabilize the resistors by temperature cycling and to cure the protective tape.

The assembled resistor and capacitor wafers are index fed to separate automatic comparison bridge checkers which check for the

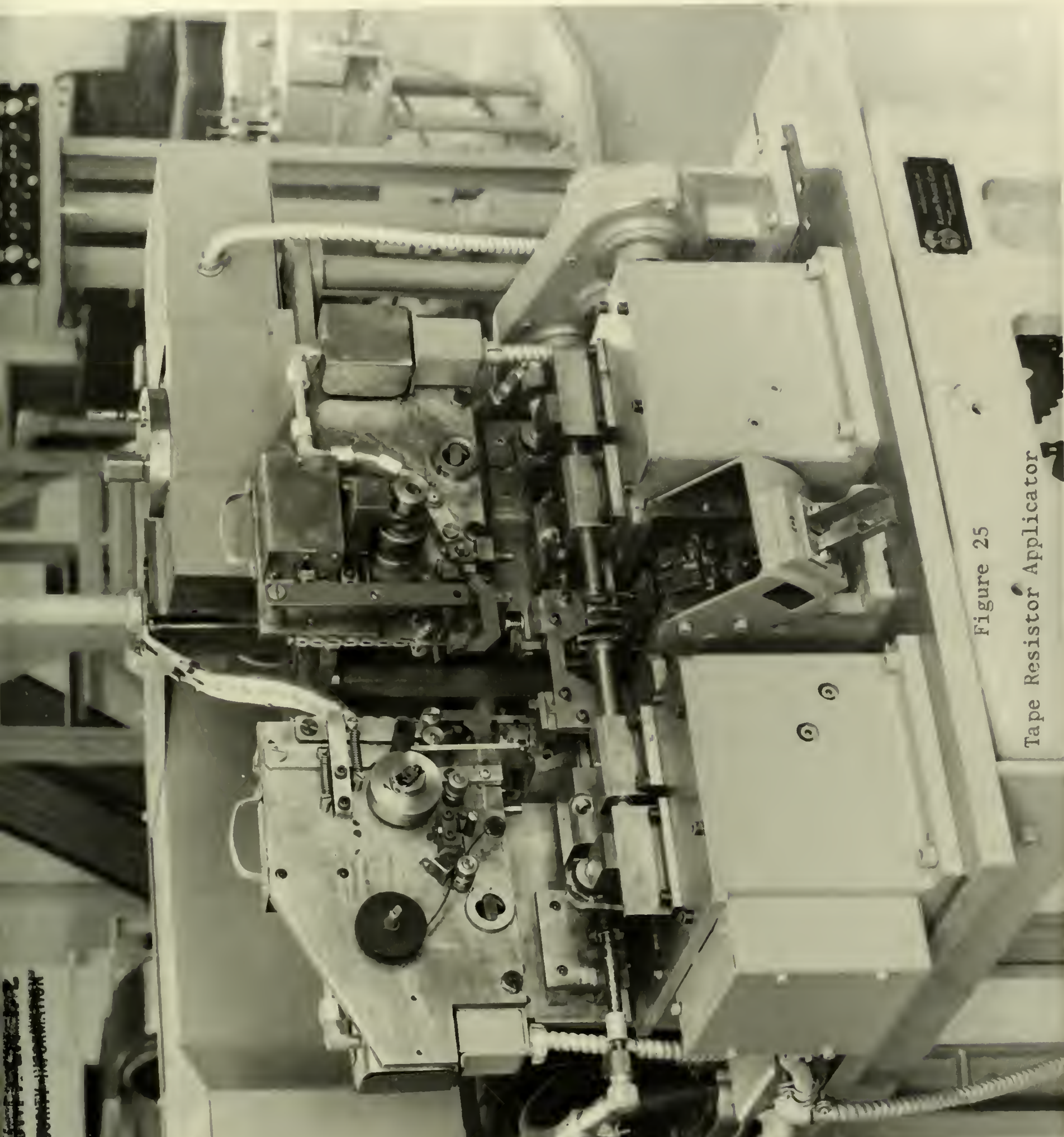

Figure 25

Tape Resistor Applicator

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proper values of resistance or capacitance between the notches of the wafers. A wafer is rejected if any component value falls outside the range of tolerances set on the comparison heads or if the pattern is different from that determined by the punched card controlling the checker. The resistor assembly tester is shown in figure (26). This figure is a very good close-up of a Syntron vibratory feeder with the indexing escapement mechanism. Also shown is the photo-electric wafer level control on the chute to the tester which causes the tester to be stopped if the supply of wafers becomes low.

No provision has been made for machine production of mylar capacitors, wire wound resistors, or inductances at the present time. However, once these components have been produced and mounted on wafers they will be handled by the machines in the same manner as the machine produced and assembled components.

The tube socket pin connectors are made from a coil of twelve mil thick and five-eighths inch wide beryllium-copper ribbon in a punch press machine which is shown in figure (27). The connectors which are made in strips are wound upon carriers which are also shown in the figure. The full carriers are placed in tempering ovens where the connector strips are heated for three hours at 500°F and then air cooled naturally. The tempered connector strips are then silver plated before assembling in the tube sockets. The wafers on which the tube sockets are to be mounted are index fed to the tube socket assembler which is shown in figure (28). The socket assembler cuts the pin connector from the strips and inserts them into the steatite

Figure 26
Transistor Assembly Tester
Vibratory Feeder.
Wafer shown in various
positions of orientation
on escapement mechanism.
Photo-electric wafer
level control shown on
chute.

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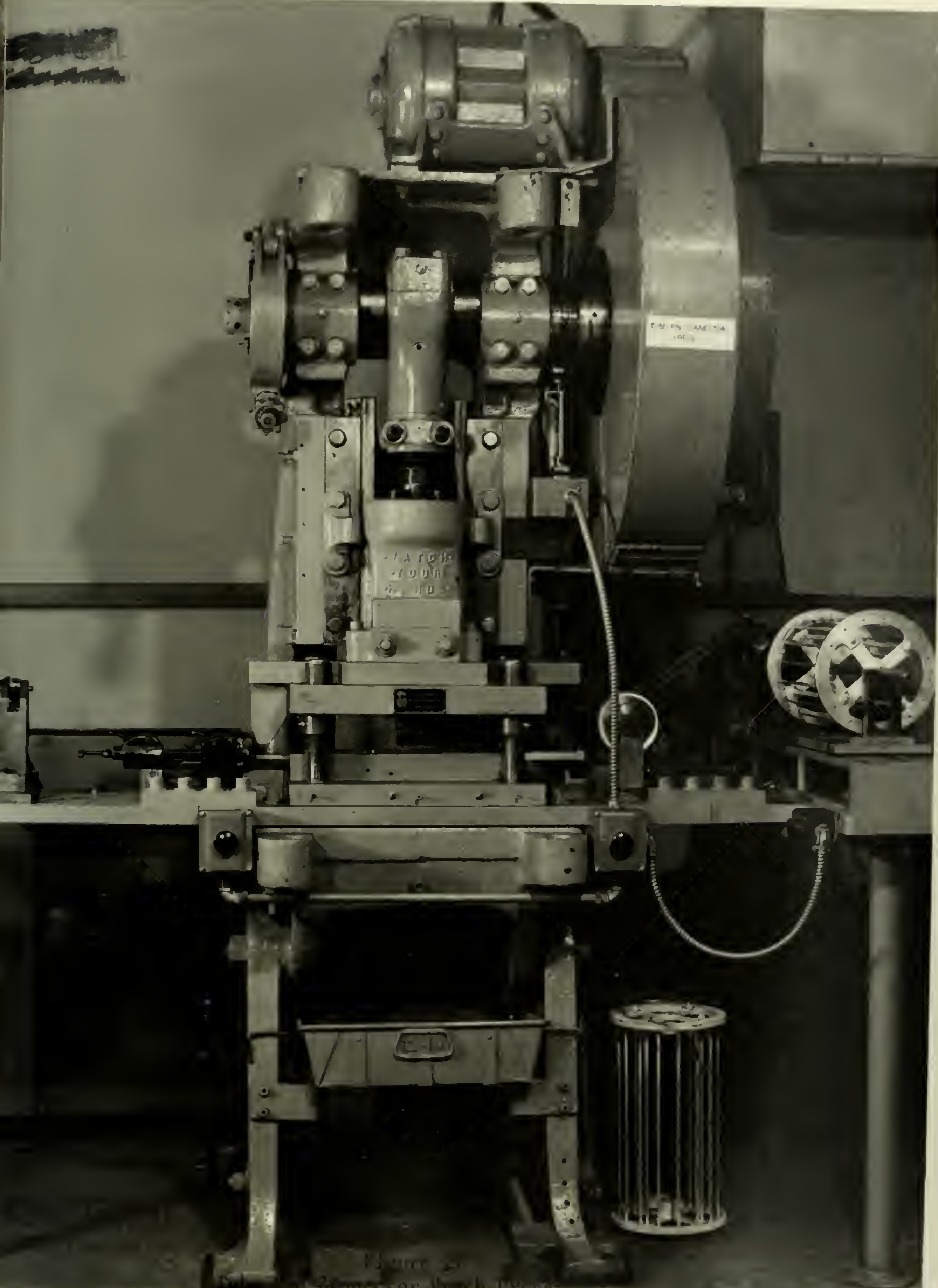

Figure [illegible]
[illegible] Connector Punch Press.

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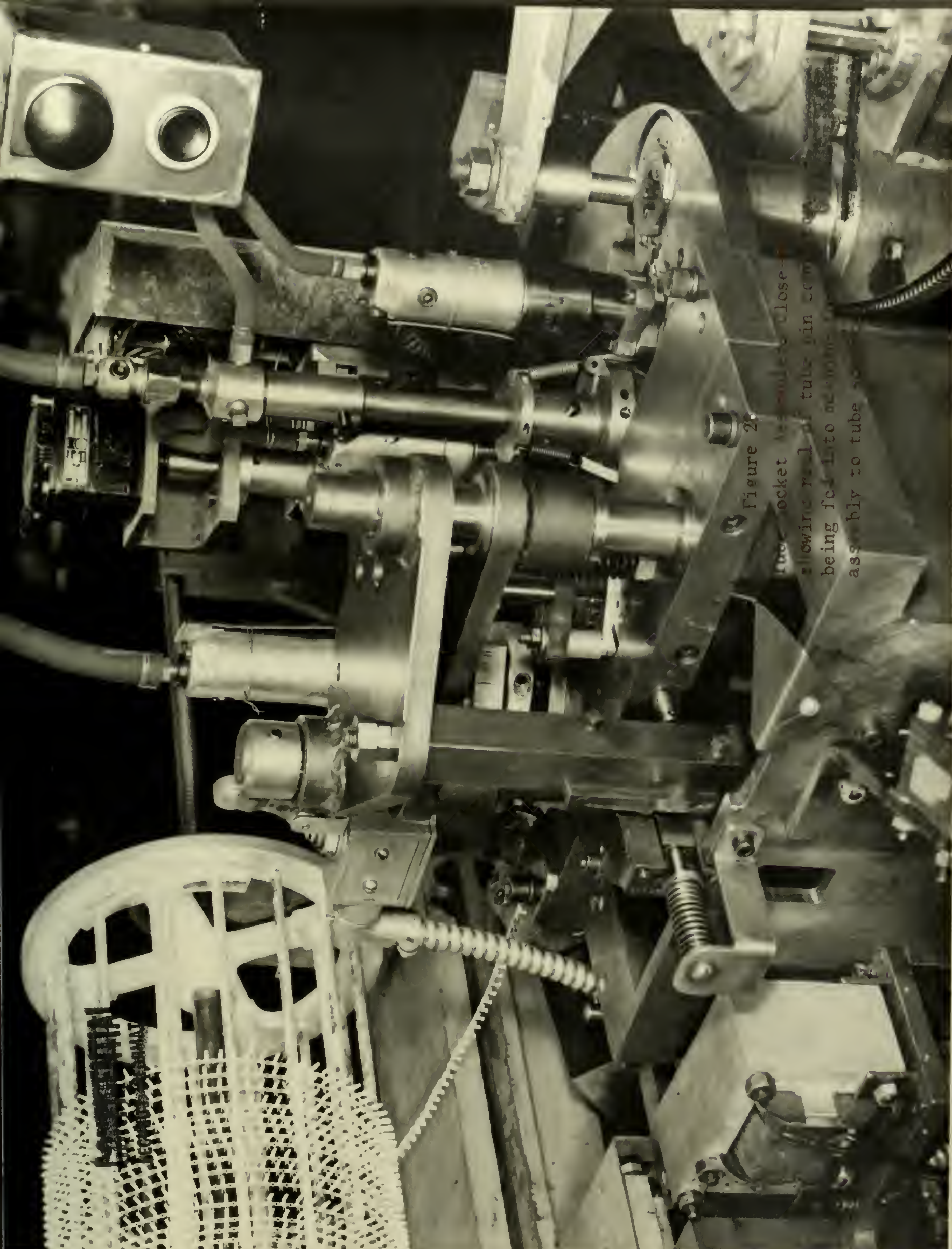

Figure 2[illegible]
[illegible] socket [illegible] close-[illegible]
showing [illegible] tube pin co[illegible]
being fed into [illegible]
assembly to tube [illegible]

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sockets. The sockets are then center riveted to the module wafers with a beryllium-copper eyelet. The tube sockets are oriented in assembly with the side which is flat parallel to one edge of the wafer.

Before the wafers are assembled in the modules it is necessary to insure that adequate solder will be in the riser wire notches to make a proper solder connection with the riser wires in the assembling process. Now that a protective coating for the tape resistor has been developed it is possible to pre-tin all wafers for soldering by a dip-solder process. A machine is currently being designed for this purpose. It is thought probable that two dippings will be necessary to insure adequate solder is deposited in the notches. Prior to this development a machine which forced small pellets of solder into the wafer notches was used for resistor wafers.

After the component wafers have been assembled and tested, and the wafer notches have been pre-tinned they are placed in the bowl feeders for the six separate channels of the module assembler which is shown in figure (29). The indexed wafers are discharged to chutes which stack them in the proper order in an assembly jig, one of which is shown in figure(30). They are carried in the jig to the first soldering station where the riser wires on two opposite sides are soldered to the wafers. The riser wires are fed to the soldering station from the large reels shown in the figures and are pressed into the wafer notches by a pair of soldering heads which heat them to melt the solder in the notches. The jig then carries the module to a second soldering station, rotating it 90°, where the soldering

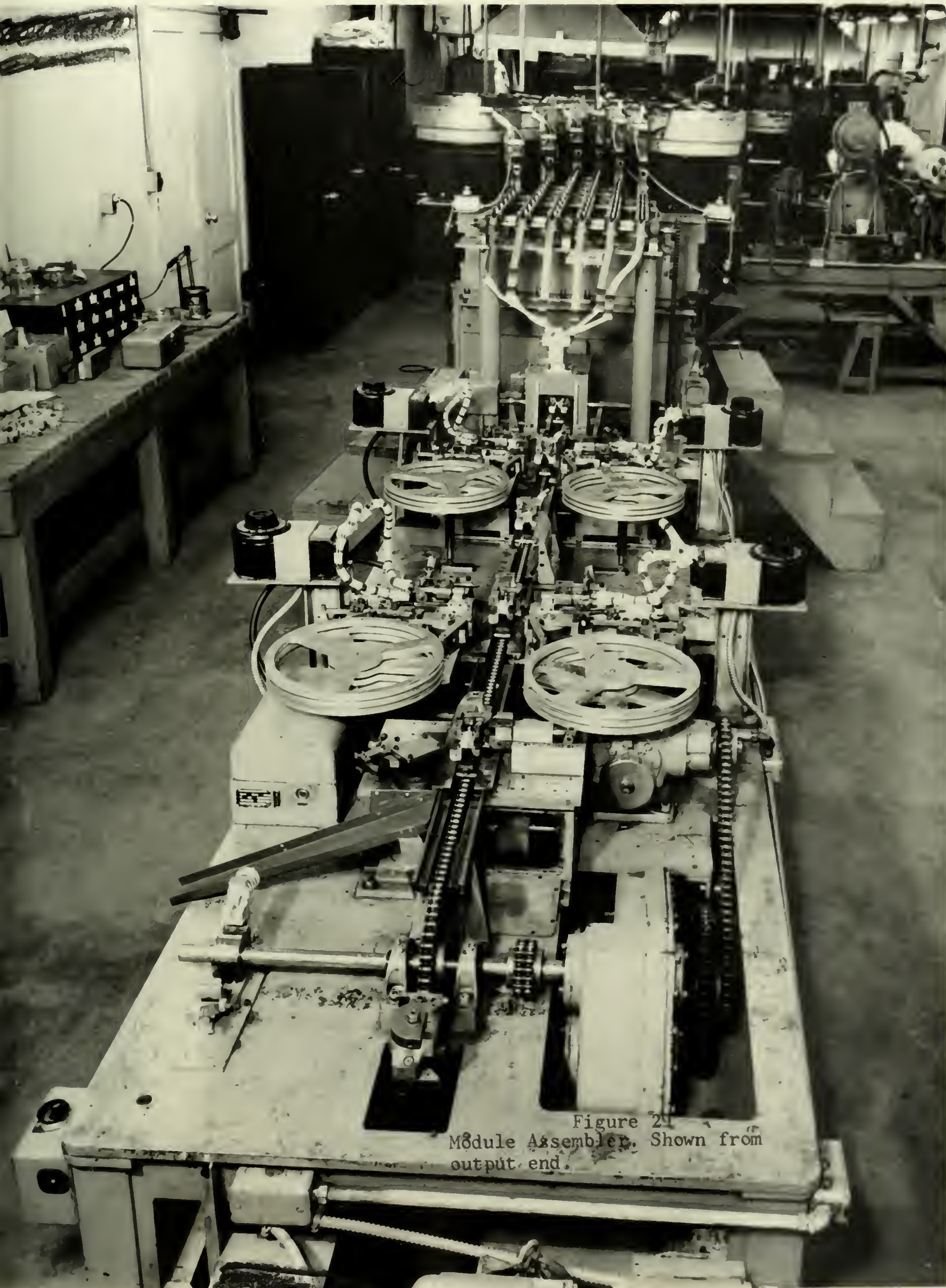

Figure 2
Module Assembler. Shown from output end.

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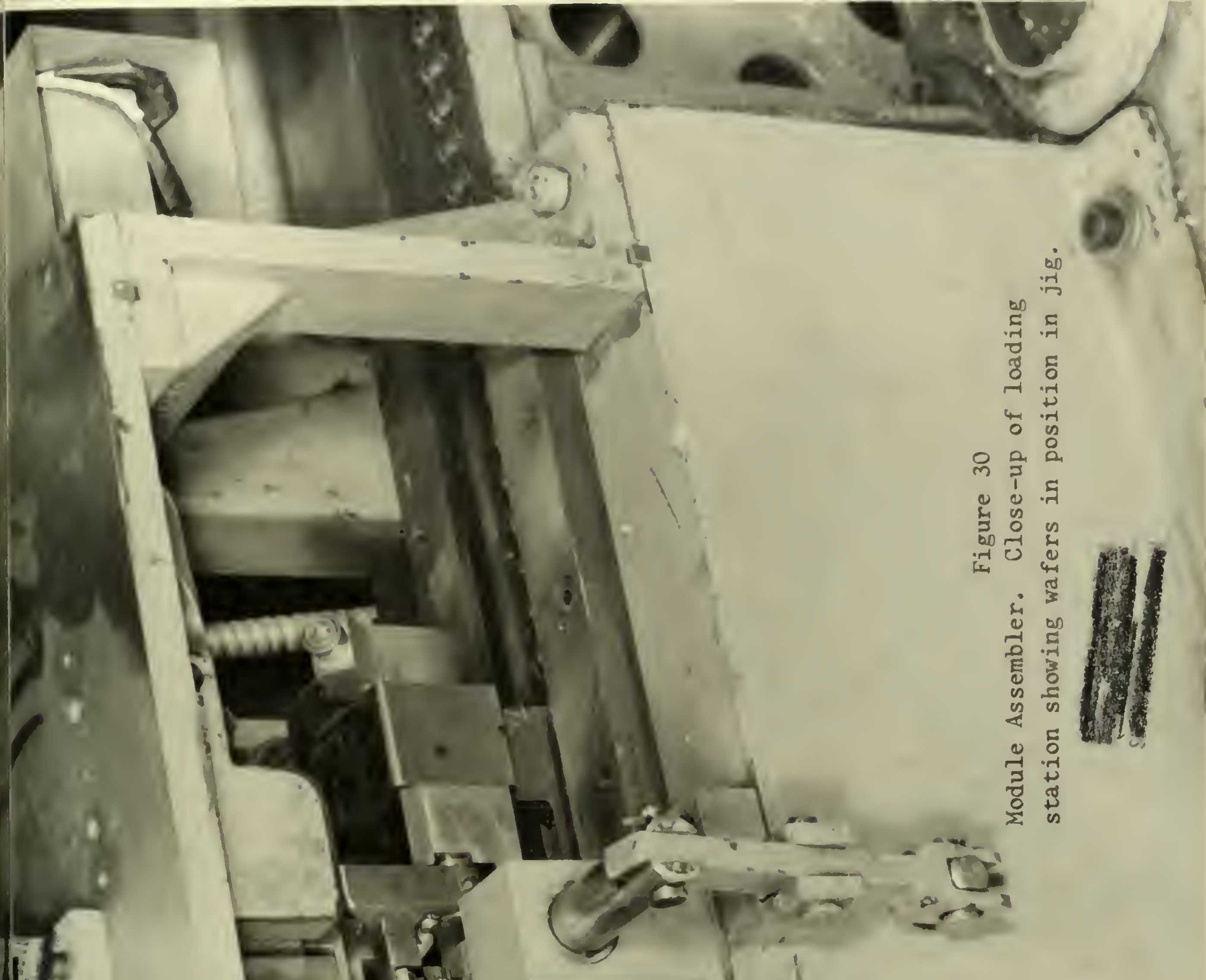

Figure 30
Module Assembler. Close-up of loading station showing wafers in position in jig.

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6 B

process is repeated for the remaining six riser wires. One of the soldering stations is shown in figure (31).

The module next passes through sets of riser wire trimming cutters which trims the ends of the riser wires to the proper length.

The assembled module is given a final a-c and d-c check in the punch card controlled automatic module checker which is shown in figure (32). The checker rejects modules not having the proper values between riser wires as determined from a standard module of the design being checked. It has been found that the checker will also reject modules having cold solder joints although it was not designed with this thought in mind.

The module is then completed in the riser wire segment clipper which cuts the risers between wafers as required.

The baseplates are stamped or cut out of XXXP Phenolic copper-clad sheets and the desired conducting pattern is etched as previously described.

The machines for assembling the modules into the plate assemblies have not yet been installed. In full production, jigs will be used to drill the holes in the baseplates for the riser wires. Other jigs will be used to hold the module in position for assembling to the baseplates. They will then be dip-soldered and the baseplates will be coated with a protective insulator.

Initially the plate assembly will be tested manually. Some thought has been given to the requirements of a method of performing these tests automatically, but as far as is known nothing has yet reached the design stage.

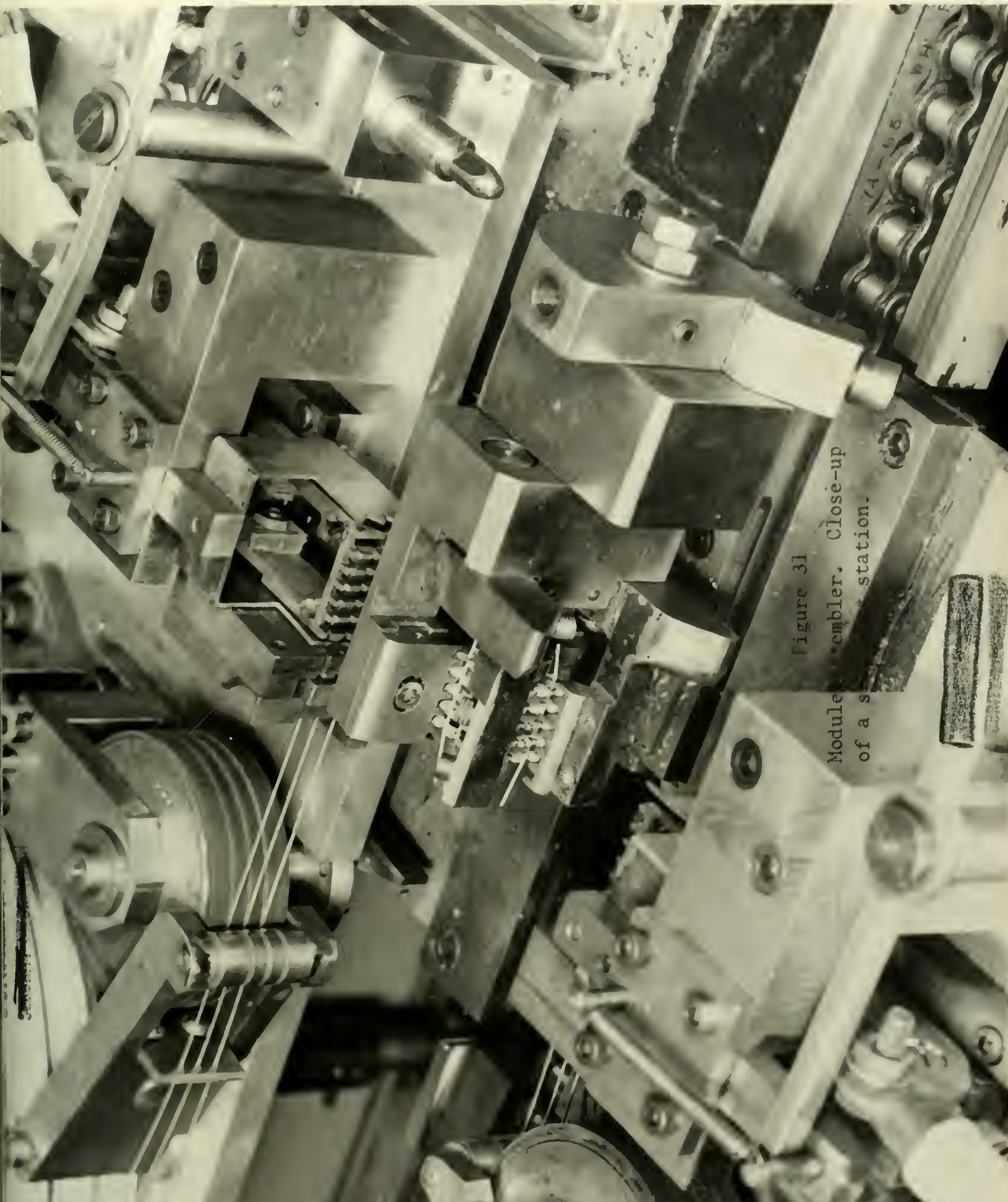

Figure 31
Module assembler. Close-up of a single station.

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Figure 32

Module Tester

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[redacted]

IV. DESIGN

In this chapter the circuit design problems and the method of laying out the module design will be discussed. Also the characteristics of the components which are important to the designer of Tinkertoy circuitry will be summarized.

The Tinkertoy system is still so new that many of the design aspects of the system have not yet been thoroughly investigated. However, in the interests of being specific, an attempt will be made to present the best information now available.

At least until more experience in making Tinkertoy layouts has been gained, the circuit should be built in a conventional breadboard layout before any attempt is made to modulize it. The breadboard is modified to eliminate from the circuit any components which are not adaptable to machine production in the Tinkertoy system. The components to be eliminated are in general large values of capacitance, high wattage resistors, power transformers, et cetera. There may be some such components which cannot be deleted, but which can be obtained in conventional components that can be packaged in non-standard modules or that can be potted in module size. Any remaining components which have not been provided for should, if possible, be arranged in the final layout so they may all be included in a non-modulized section with any necessary mechanical components.

It may be possible to reduce the size of the large capacitors by raising the network impedances while maintaining similar time constants.

[redacted]

[redacted]

The standard one-half watt resistor can usually be replaced by the one-quarter watt tape resistor, but since this is not always true each one should be considered individually. Probably some of the slightly larger resistors may also be safely reduced to a slightly lower power rating which can be more easily modulized by using series and parallel combinations of the tape resistors. It may be found that essentially the same performance is obtained with the tubes biased for slightly lower quiescent plate currents, permitting use of lower power load resistors which are better adapted for modulizing. In making any of these changes, however, the accepted design standards should be followed. A study of the specific circuit may suggest a number of other ways in which it may be modified to be more adaptable for complete modulization.

After the conventional breadboard has been modified or redesigned it is used as a guide in making the module layout. It may be found that the circuit will require further modification after it has been built in the module form. A number of module layouts may be tried before obtaining the most satisfactory layout. Just as in building conventional circuits, it has been found that the layout problems are relatively simple for audio frequencies, but greater care is required as the frequencies involved become higher. As experience is gained, less trial and error should be required to solve the layout problems.

In general, a greater shunt capacitance is obtained across the input and output circuits of the stages with module layout than with careful conventional layout. However, the stray shunting capacitance will remain nearly constant in the machine produced units so that once

[redacted]

the value has been determined it may enter into the design just as a lumped capacitance. Typical values of stray capacitance, which an engineer at Sanders Associates measured in a sixty megacycle I.F. stage, are given in table IV.

At high frequencies it has been observed that the various lengths of parallel riser wires will act as stubs, which may produce low shunting impedances across high impedance circuits at certain frequencies. This effect can generally be minimized by altering the layout so that it will not occur at frequencies of interest.

The Tinkertoy components have been developed with the aim of permitting operation at higher ambient temperatures than is possible with present conventional components. The Tinkertoy system of construction also permits better natural heat dissipation if full advantage is taken of the possibilities. In one particular equipment which was redesigned it was possible to eliminate the forced air blower used in the original equipment and at the same time to maintain a lower internal ambient temperature.

A number of forms have been developed to assist in the mechanics of the module layout. Two different forms for accomplishing the same result but slightly different in format are given in the next two pages. The component electrical symbols labeled with the proper values and identifying numbers are drawn in the wafer symbols on the first form or in the rectangular blocks on the second form. The riser wire connections and the points where the risers are to be clipped are indicated in the center diagrams of both forms. Layouts of the baseplates

[redacted]

TABLE IV

Source of Stray Capacity	mmf	Remarks
Between adjacent tube pin connections	0.5-0.7	Standard 7 pin tube socket. Excessive solder on joints from wafer slots to tube pins increases the capacity from 0.1-0.2 mmf.
Between alternate tube pin connections	0.3-0.5	
Between surface of etched coil and 3/8" silver screen on bottom of adjacent wafer	0.5-0.7	Using a 6 turn copper etched coil with .01" wire and .01" spacing.
Between two 3/8" silver screens on top and bottom of adjacent wafers	0.4-0.5	
Any one tube pin connector to surface of etched coil on bottom of same wafer	0.8-1.0	If several tube pins are at low r.f. potential, the total shunt capacity may be unusually high
Any tube pin connector to etched coil on bottom of adjacent wafer	0.4-0.6	
Between 1/8" wide and 1/2" long interstage base plate connection and ground plane spaced 1/16" from connection	0.7-1.2	Excessive solder on joints also causes this effect to be exaggerated
Between adjacent riser wires extending along standard 5 wafer stack;	0.7	Increases slightly due to excessive solder on wafer slots
between alternate risers	0.4	
Between any one tube pin connector and grounded rivet on tube socket	0.5	
Between any one tube pin and 3/8" silver screen on bottom of adjacent wafer	0.3-0.4	
Between two condensers on top and bottom of adjacent wafers respectively (3/8" silver screen, 1/16" spacing between screens)	0.7-0.9	If one of the condensers is a coupling condenser, this amounts to shunting the stray capacitance across the interstage coil

Note: Remaining sources of capacity may result in an additional 1.5 to 2.5 mmf although each source is small (0.1 to 0.2 mmf).

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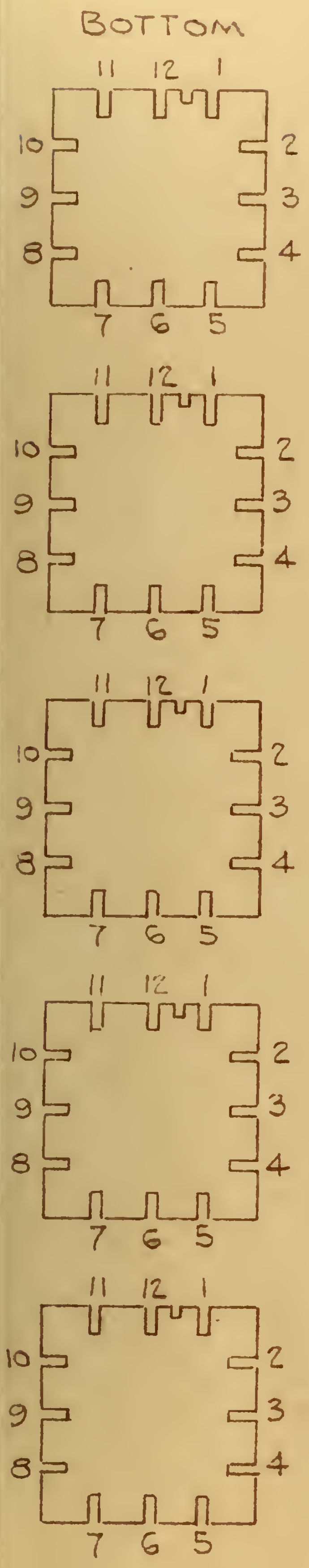
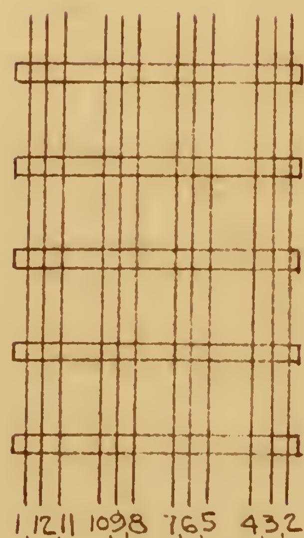
TITLE: PROJECT:





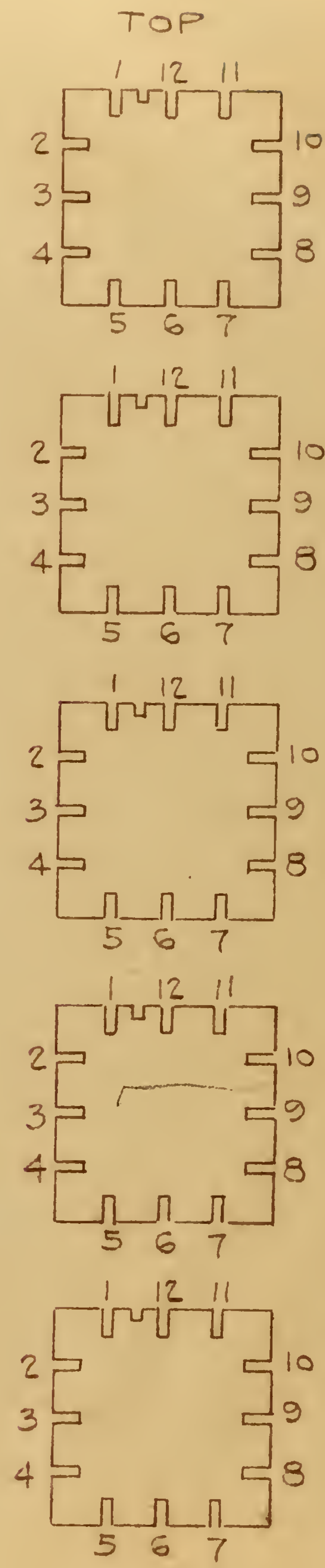


Figure 33
Module layout sheet.

DESIGNED		DRAWN		CHECKED	
INITIAL	DATE	INITIAL	DATE	INITIAL	DATE

	MODULE	PLATE	EQUIP.
FILE			

MODULAR WORK SHEET

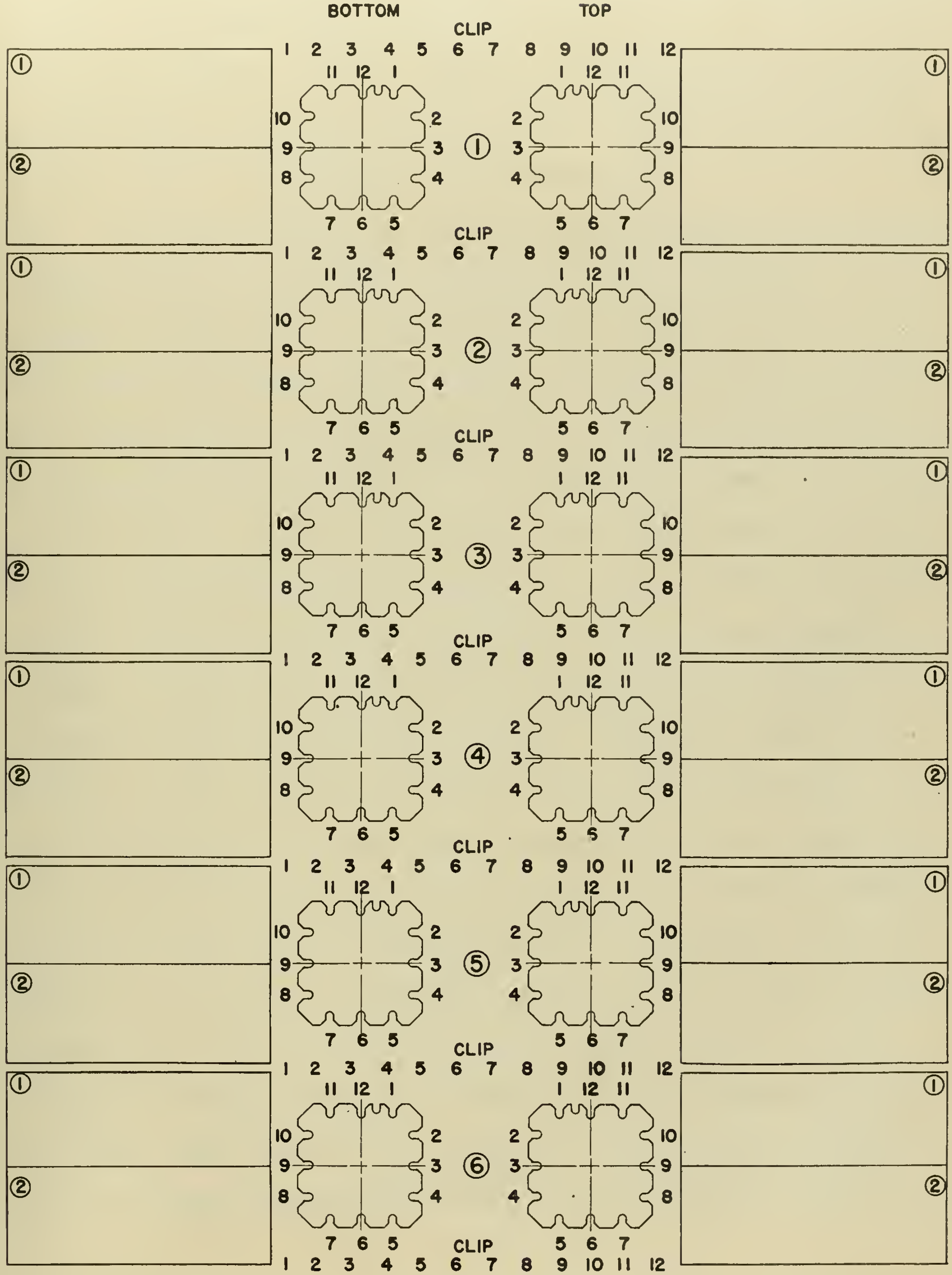


Figure 34

should be made to assist in determining the riser wire connections to be made to the conductor patterns. The patterns are sketched on the layout to insure that all required connections can be made without crossovers and to insure that signal leads are kept short and well separated from other leads and each other to prevent interaction.

In designing the module layout the points of the circuit which are to be connected to each riser wire should first be determined. This calls for consideration of the orientation of the tube socket to provide the best layout. With the nine-pin socket the riser wires going to each connector are determined by the orientation, but a choice of which riser of each corner pair is connected to the tube socket remains to be made with the seven-pin socket. Where sub-miniature tubes with solder type leads are used the sequence of leads should be kept, but more freedom is permitted in the layout. The tube base orientation should be such that the signal leads, which are normally etched on the top baseplate, are kept short and well separated, without sharp turns. No leads should be required to cross outside the module.

A voltage may be transferred from one riser wire to another by a connection silvered on one of the wafers if this becomes desirable. In such a case only part of each riser may be required to carry the voltage so if desired they may be cut between a pair of wafers, permitting the remaining portions to carry another voltage or to be grounded. Supply voltage leads should not be run through one module to make connections to other modules if it can be avoided. Double clad baseplates with circuits etched on both sides may be used, if

necessary, but is undesirable from the standpoint of increased cost and greater complication in production.

In assigning riser wire connections, the desirability of keeping lead lengths in the module as well as on the baseplates as short as possible must be considered.

The critical circuit riser wires may be surrounded by grounded risers. The input and output leads should be kept separated as far as practical. The signal leads should be kept separated from supply voltage leads, usually by using the upper baseplate for signal leads only.

Once the choice of riser wires has been made to meet the above needs, the remaining risers may be assigned as desired to complete the circuit connections not yet determined. Risers may be cut between wafers or at the ends, if desired, instead of going to the baseplates, leaving sufficient wires to provide adequate support to the module. Not all connections between risers are permissible on resistor wafers so that some of the choices previously made may have to be changed to avoid these combinations. Those riser wires not otherwise used should in general be grounded.

After this tentative assignment of the various circuit connections to riser wires has been made, the remainder of the layout may be completed in a fairly straight forward manner. The following considerations should be kept in mind while making the assignment of the circuit components to the various wafers.

1. Tube sockets must be mounted on the outside of an end wafer, normally the top one.

[redacted]

2. Variable components should be mounted on an end wafer with access to adjustments normally through the plane of the wafer.
3. The outside face of the end wafers should normally not be used for components thicker than resistors, except for tube sockets.
4. The number of components per wafer should be kept to a minimum for best yield percentage of good wafers.
5. The maximum number of resistors per wafer is two per side, except the rated power dissipation of the wafer is limited to three-quarters of a watt. The resistors on the same face of the wafer must be placed physically parallel, but may be placed parallel or perpendicular to those on the reverse face. Resistance values falling outside the available range from forty ohms to ten megohms may be obtained using parallel or series combinations. For resistances requiring closer tolerances than ten per cent wire-wound resistors should be used. For power ratings greater than one-quarter watt, series or parallel combinations of tape resistors may be used. The limited space for painting connections when two resistors are placed upon the face of a wafer permits each end of a resistor to be connected only to the four notches at that corner of the wafer.
6. The various ceramic capacitor combinations on one face of a wafer is limited to one large disc, two small discs placed

[redacted]

diagonally, or one large disc with another large or small disc stacked on it. The capacitance available with disc capacitors is limited to the range from 7mmf to 20 mmf with small discs and up to .01 mf with large discs. The range may be extended by parallel combinations to a maximum value per wafer of .05 mf obtained by placing two stacked .01 mf capacitors on each side of the wafer. The high dielectric constant ceramic capacitors have poor temperature stability so that for purposes where good stability is required mylar film or conventional capacitors must be used. Mylar film capacitors are available from 680 mmf to .02 mf. Because of the size of these capacitors only resistors are sufficiently thin to be used on the adjacent face of the next wafer. Sectored ceramic discs may be used to provide several capacitors having a common terminal on the same body, if desired. Capacitors which are stacked must have at least one common connection. The potential on the adjacent wafer should be kept about the same as the outer plate of stacked disc capacitors to prevent arc-over due to the close tolerances. Precautions must be taken to minimize undesired coupling between capacitors by carefully choosing the capacitors placed on the same wafer. If one plate is grounded it should be placed between the capacitors. The coupling between capacitors on the two sides of the same wafer with a ground plane between is normally of the order of 4 mmf.

[illegible] The [illegible] capacitors [illegible] in the range from [illegible] small [illegible] The [illegible] may be [illegible] ceramic [illegible] on each side of the [illegible]. The high dielectric constant [illegible] capacitors are available [illegible].

[illegible] capacitors [illegible].

[illegible]

[redacted]

7. The baseplate design should be such as to provide the shortest possible signal lead connections consistent with maintaining adequte separation between the conductors. Sharp angles should be avoided in conductors carrying high frequencies. In general, the top baseplate should be reserved for signal carrying leads and the bottom baseplate should be used for power supply leads. Room is not available to permit conductors to pass between adjacent riser wires making connections to the baseplate, but direct connections may be made between two riser wires on opposite sides of the module if an interfering tube is not mounted through the baseplate. Where it is not necessary to etch the baseplate copper away, it is generally left to provide a large ground plane.

Pictures included in the following pages provide a comparison of the modular method of construction as compared to more conventional methods. In figure (35) two five-microsecond delay lines constructed in both systems and having about the same characteristics are shown. The distributed constant line occupies a slightly greater volume than the module line which, with slight modification, could be reduced further in size, if desired. The second picture, figure (36), provides a comparison of a circuit constructed in the two systems. The five modules shown contain the circuit components except for the sub-miniature tubes which are mounted in holes drilled in the aluminum semi-circular ring shown around the sub-assembly. The third picture, figure (37), is of an FM receiver shown in both the conventional and modulized versions.

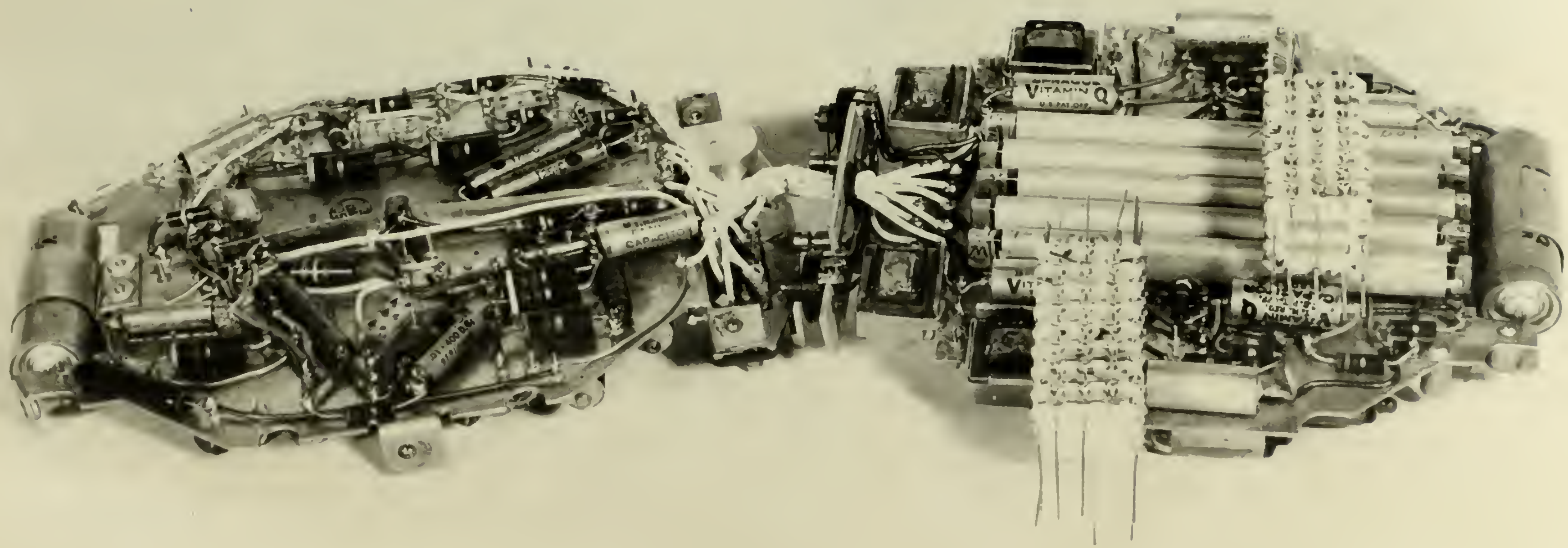


Figure 35

Conventional and modulized version of a five microsecond delay line.

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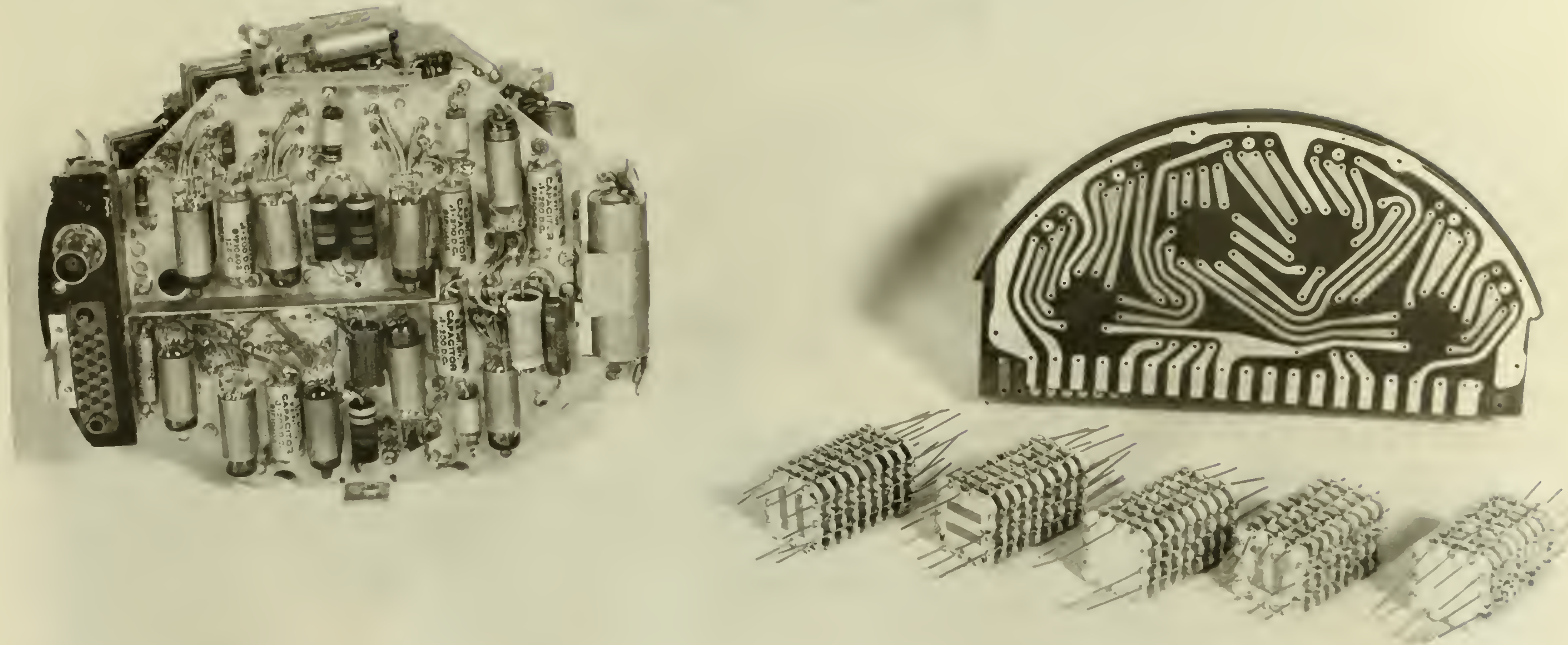

Figure 36

Miniaturized and Modulized Construction of Same Circuit (Baseplate shown is from another circuit of same equipment).

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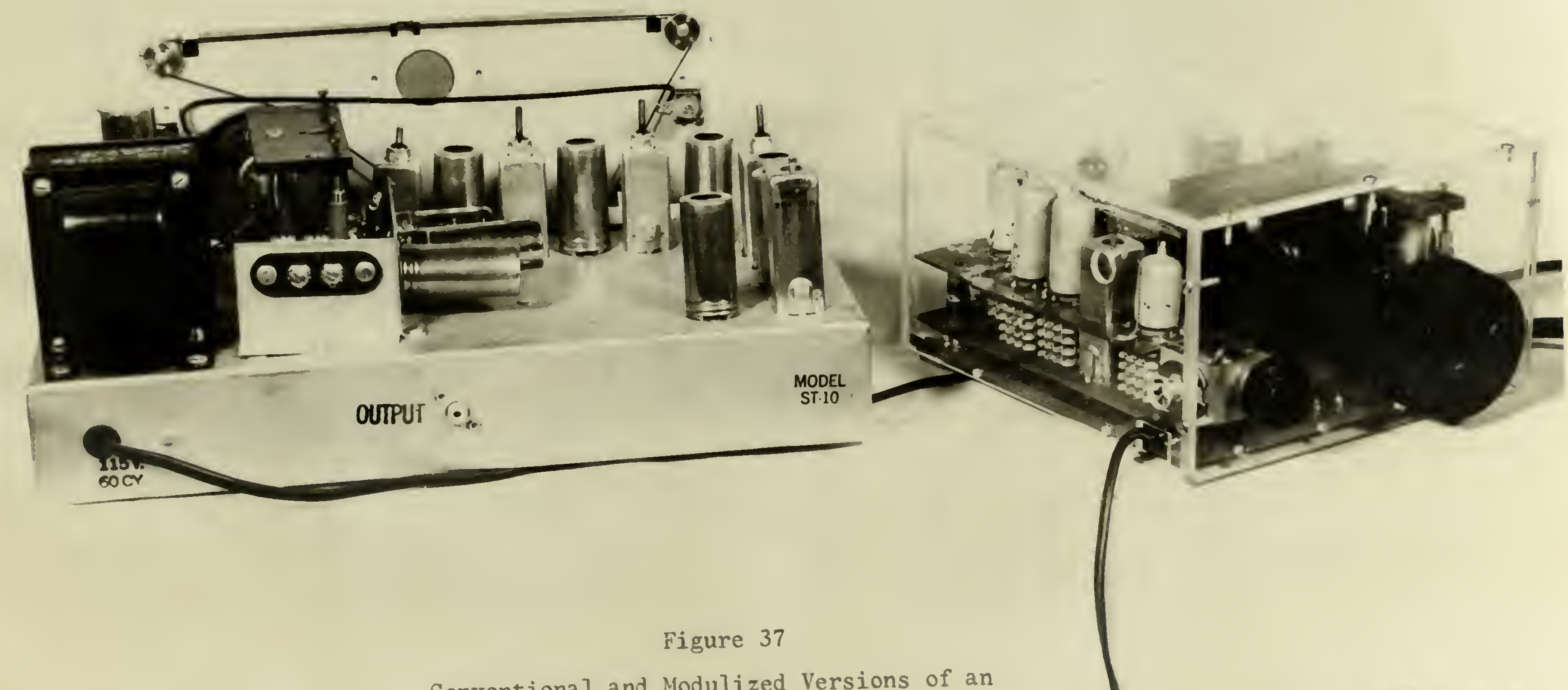

Figure 37

Conventional and Modulized Versions of an FM Receiver.

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The last two pictures, figures (38) and (39), are of a drone control receiver. It is the first equipment to be initially designed in the Tinkertoy system. The plate assemblies of various sizes and shapes should be noted in these figures.

The component specifications of interest to the design engineer will be summarized in the remaining pages of this chapter.

1. Wafers

   (a) 7/8" x 7/8" x 1/16" with clear area for mounting components of at least 9/16" x 9/16". Spacing between wafers normally 1/8" but can be increased to 5/16" by removal of one wafer.

   (b) Weight: 1.2 gm.

   (c) Power dissipation limited to 3/4 watt. Dielectric constant about one.

2. Tube sockets

   (a) Miniature 7 or 9 pin. Have choice of module riser wires connected to the 7 pin socket at the corners of the wafer. Tube socket flat to be mounted parallel to wafer edge.

   (b) Diameter 0.687", height 0.33".

   (c) Weight: 3.65 gm.

   (d) Stray capacity between two contacts about 0.6 mmf and from one to all others 0.8 mmf. Leakage resistance between two contacts about 7 x 10^{11} ohms and from one to all others 5 x 10^{11} ohms.

3. Capacitors

   (a) Ceramic disc capacitors.

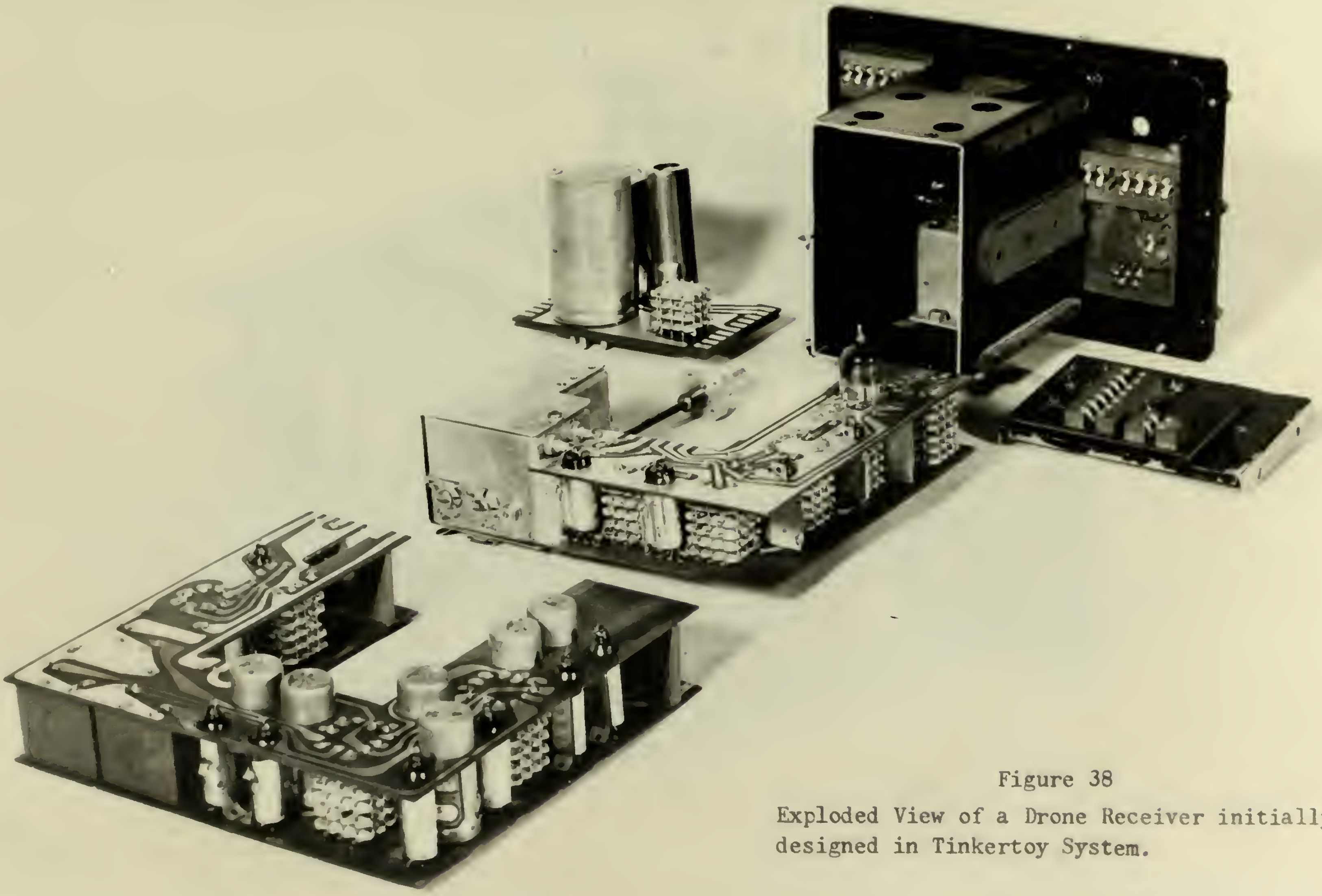

Figure 38
Exploded View of a Drone Receiver initially designed in Tinkertoy System.

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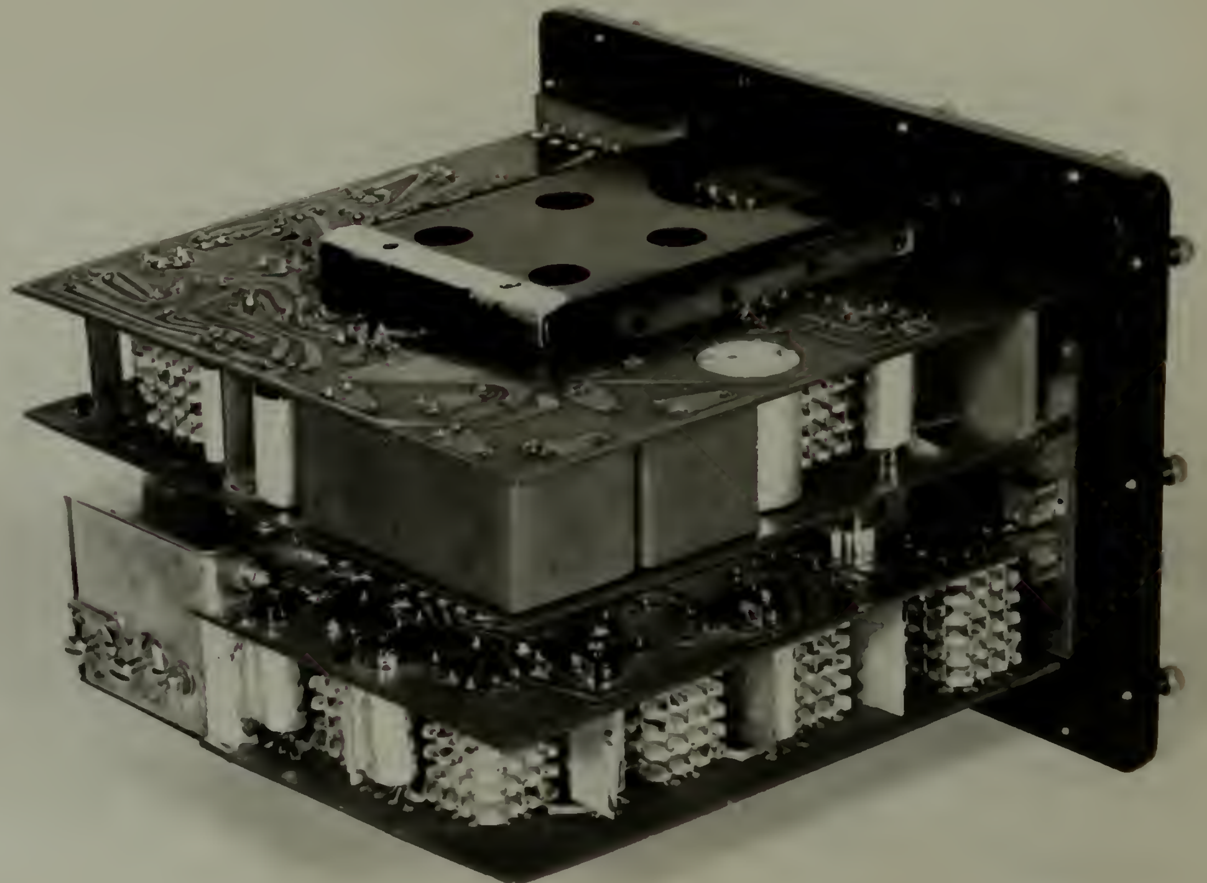

Figure 39

Assembled View of Drone Receiver (without case).

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(1) Diameter 0.3" or 0.55" and 18 mils thick.

(2) Weight: Silvered and tinned 0.2 and 0.6 gm.

(3) Range: With small disc 7 mmf to 20 mmf and with large disc 20 mmf to .01 mf in all RMA standard 10% values. Temperature compensating capacitors from 5 mmf to 200 mmf. Accuracy: Within 10% at room temperature (5% with special care). High values fall off appreciably at high temperatures.

(4) Rated 500 working volts continuous at temperatures up to 85°C.

(5) Bodies with dielectric constant above K500 decay in capacitance value with shelf life.

(6) Power factor: Approximately constant with frequency.

: At 25°C varies with dielectric constant less than 2% for K5000, less than 1% for K2000 to K100, less than .04% for K88, and approaches mica below K50.

: Varies with temperature. In general increases linearly for bodies below K500. For higher dielectric constant bodies is a complex variation with a general decrease to a minimum between 100°C to 150°C and returns to original between 150 to 200°C.

(b) Mylar film capacitors

(1) Up to 9/16" x 9/16" and 90 mils thick.

(2) Range: 680 mmf to.02 mf.

(3) Rated up to 600 volts.

(4) Capacitance stable with temperature. Variation of dielectric constant of film with frequency in figure (40).

4. Resistors

(a) Tape resistors:

(1) About 0.125" x 0.5" and six mils thick, 0.3" spacing between electrodes on wafer.

(2) Weight: About 0.02 gm.

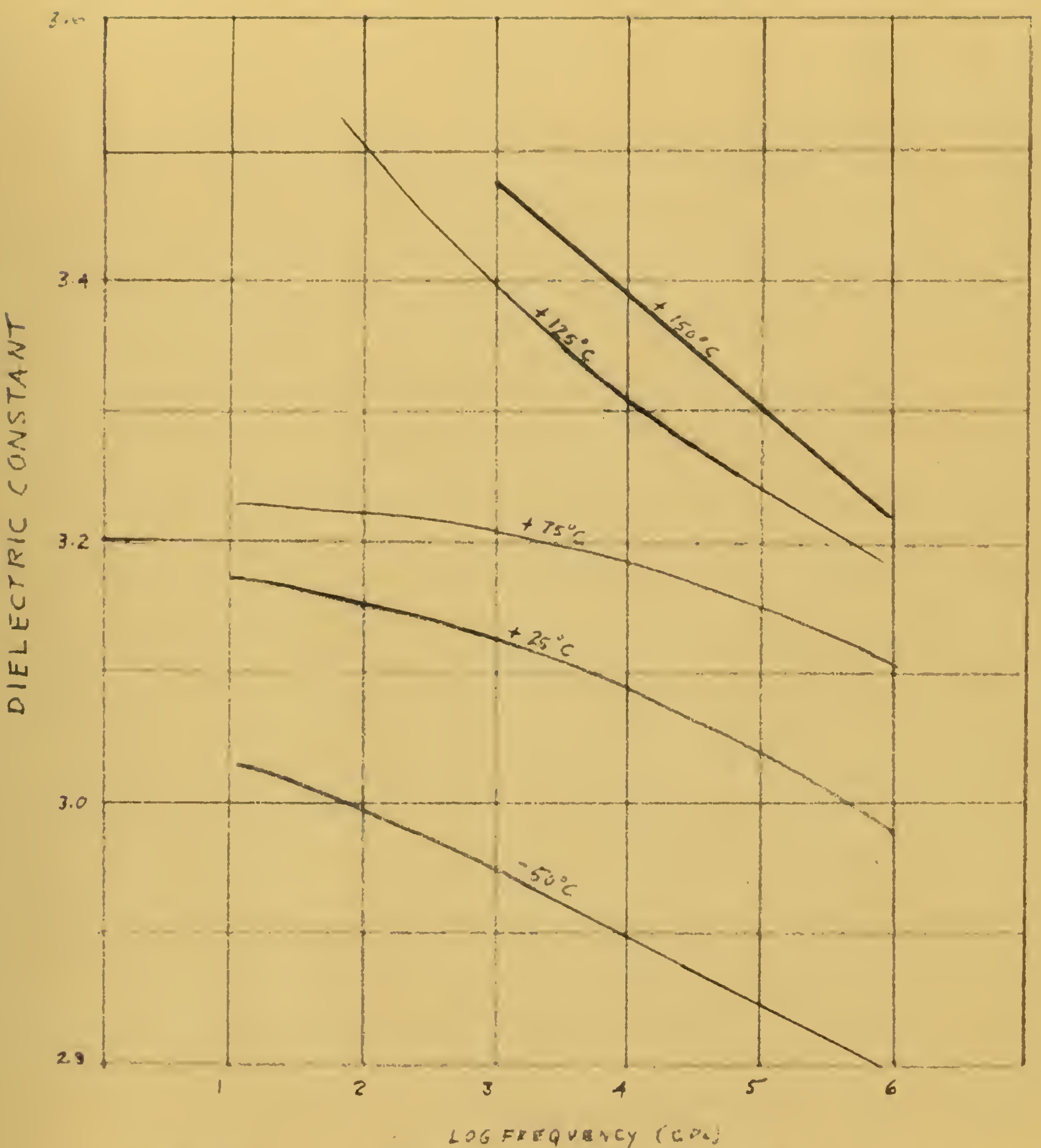
(3) Rated 1/4 watt up to 200°C. See figure (41) for derating curve.

(4) Range: Forty ohms to ten megohms.
Accuracy: Within 10%.

(5) Stray capacity 3/4 mmf between two on same side of wafer and 3 mmf from one to all others possible. Leakage resistance between two on same side 15 x 10^{11} ohms. Temperature cycling five times from 25°C to 200°C results in less than 1% variation. Have less than 6% change when operated for 500 hours under 1/4 watt load at rated maximum temperature.

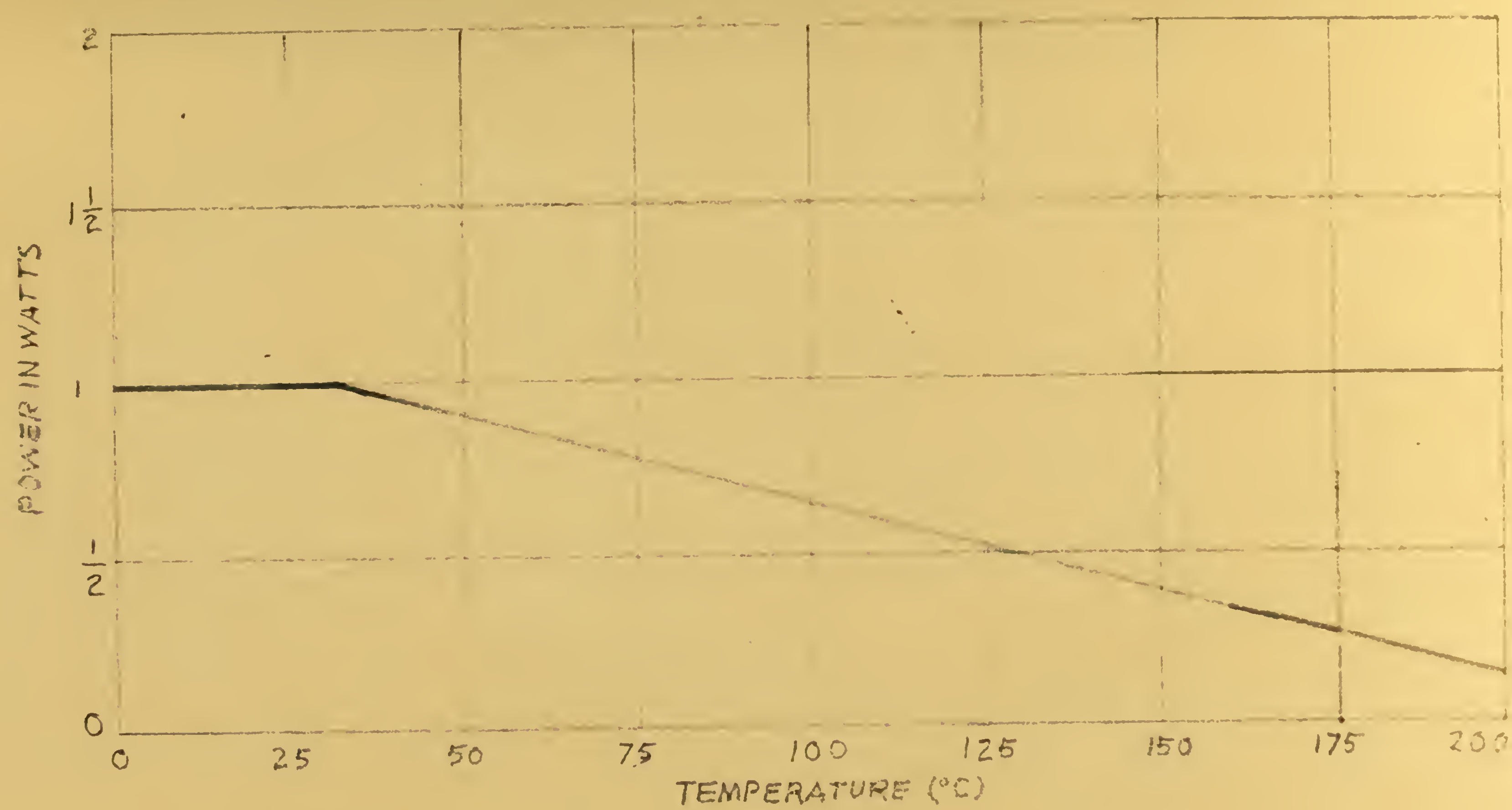
(6) For the 150° series: Temperature coefficient negative 500ppm/°C. Voltage coefficient 0.035%/ volt below 2.5M and less than .05%/ volt from 2.5M to 10M. Noise less than lmvolt/volt from 5K to 100K and less than 3mvolt/volt from 100K to 1M.

(7) For the 200°C series: Temperature coefficient positive



CHANGE IN DIELECTRIC CONSTANT OF MYLAR WITH FREQUENCY FOR DIFFERENT TEMPERATURES

Figure 40



TEMPERATURE DERATING CURVE FOR NBS RESISTORS

Figure 41

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1000 ppm/^{o}C from 100 ohms to 100K and same as 150^{o}C series above 100K. Voltage coefficient 0.035% from 1K to 500K. Noise less than lmvolt/volt from 1K to 50K, and less than 3 mvolt/volt from 50K to 250K.

(b) Wire wound resistors: To be available from about one ohm to 2Megohm with 1% accuracy.

5. Other components.

(a) Fitted in clear area of at least 9/16" x 9/16" on wafer, clear height of 1/8" which is increased 3/16" for each wafer omitted.

(b) Variable components on end wafers with access for adjustments through plane of wafer.

6. Module assembly:

(a) Standardized on five wafer stacks, but other sizes can be used. The five wafer stack 13/16" high or with tube base 1 5/64" high.

(b) Weight of five wafer stack without components 11.2 gm.

(c) No standardized provision for shielding. Self inductance of one riser wire at 100 Mc with no connections is about .05 mh and with adjacent wire used as ground for first is about 0.013 mh. Leakage resistance one wire to any other 5 x 10^{11}ohms and to all others in module 2 x 10^{11}ohms. Stray capacity one riser wire to any other about 0.7mmf and to all others about 2.0mmf.

7. Plate assemblies:

(a) Ten or less modules or equivalents with minimum on center spacing of 1".

(b) Minimum conductor widths and spacings on order of 50 mils.

(c) Tube shield bases riveted to baseplates.

[redacted]

V. CONCLUSIONS

The primary purpose of the Tinkertoy project is to develop a practical and flexible system of machine production of electronic circuitry from basic materials. After the production line has been completed and used to produce a selected military electronic equipment which may be used to prove the practicability of the system, it is planned to reveal the development to industry. This is with the hope that industry will accept the fact that machine production methods have finally arrived and will use this sytem or some other system of machine production and proceed to make continued improvements. Plans are already being made for extending the system further, but it is hoped that once the industry becomes aware of the many advantages to be gained that it will no longer be necessary to lead the way.

There are very compelling reasons for the system to be accepted by industry. A small company with little capital outlay for the relatively inexpensive machines and a small plant layout could easily out produce the larger companies now using the slower hand assembly techniques. If the expectations are realized, the resulting equipments will be equal to or better than the present equipments at a fraction of the cost and with decreased usage of hard to obtain critical materials. By suitable standardization with development of plug-in assemblies for making up a complete equipment, repairs can largely be reduced to replacement of the relatively cheap plug-in assemblies as is now done with vacuum tubes.

As applied to military equipment these same advantages will apply

with the additional advantages of having more rugged equipment which, if expectations are met, will at the same time be lighter and smaller than the present equipment.

This type of construction in which the equipment is made up of functional sub-assemblies should add impetus to the present trends toward standardization of circuits. With standardization extended to include all equipments installed on shipboard or carried by any military unit, the spare parts required could be largely reduced to carrying suitable numbers of functional sub-assemblies of which a number would be common to several equipments. The reliability of the equipment could be greatly increased, even if the present rate of failures were to continue, for the replacement of a complete sub-assembly found to be faulty could be accomplished in a fraction of the time now needed to locate the particular faulty part and replace it. By incorporating a fault-finding system which could isolate the trouble to one or two such sub-assemblies, repairs could be speeded up even more.

Circuit standardization could also be used to greatly speed up design of new equipments for the basic equipment would already be determined and only the circuits peculiar to the particular requirements would need to be designed. The development of standard circuits should not be allowed to stifle development, however, but efforts should be continued to improve upon the standard assemblies. By such methods the existing equipments after conversion to standard sub-assemblies could be kept modernized by continued replacement of the individual sub-assemblies as they are improved.

The number of electronics technicians required to maintain equip-

ment with standardized sub-assemblies should be greatly reduced. The training required of the maintenance personnel would be reduced to such an extent that the operators with a little training should be capable of performing all but the most complicated repair work. The number of circuits with which the technician performing the major repair work need be familiar would be reduced to the few standard circuits plus the special circuits peculiar to particular types of equipment. This same standardization could also be used to reduce the size and speed up preparation of the instruction books which would only need to treat the special circuits and their relation to the standard circuits used.

Returning to the major reason for which the Tinkertoy system was developed, the stockpiling of a number of the production machines which are relatively inexpensive will permit rapid expansion of the electronics industrial capacity in the event of mobilization for war. This should reduce if not completely eliminate the need to stockpile large quantities of expensive complex equipment which may rapidly become obsolete.

The machines are sufficiently small that they could be hurriedly installed in the smallest factories in case of war and start producing circuits in large volume in a fraction of the time normally required to train workers to do the same job. Most of the materials used are available in ample quantities. The use of critical materials is held to a minimum. If it becomes desirable the small quantities of waste materials in the production process could be reclaimed.

This system of machine production will certainly make possible a large step forward in the rapid production of electronic equipment.

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However, until every part of electronic equipment can be similarly machine produced the ultimate solution will not have been reached.

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